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THE LIVING WORLD

THE LIVING WORLD

by

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CONTENTS

(showing the main topics in each chapter)

CHAPTER PAGE

I. PREVIEW OF LIFE 1
Environment; organisms; protoplasm; cell-structure.

II. GREEN FLOWERING PLANTS 14
Structure of root and shoot.

III. TREES 39
Deciduous and evergreen; secondary thickening; structure of twigs; typical British trees through the seasons.

IV. ENERGY AND LIFE 56
Measurement of energy; chemical energy; respiration and burning; carbon cycle; storage of energy.

V. FOOD AND FEEDING 65
Classes of food; nature of carbohydrates, fats and proteins; nitrogen cycle; vitamins; water in organisms; diet.

VI. HOW PLANTS WORK—I. 85
Water in plants; osmosis, conduction, transpiration; stomata; respiration.

VII. HOW PLANTS WORK—II. 97
Carbon assimilation; food storage and vegetative propagation; plants as animal and human food.

VIII. MAMMALS (chiefly illustrated by the rabbit) . 110
External features; life-history; skeleton; muscular movement.

IX. DIGESTIVE SYSTEMS OF MAMMALS . . . 125
Layout of internal organs; digestive processes; enzymes; ruminants.

X. BREATHING AND CIRCULATION IN MAMMALS . 135
Respiration; circulation; blood.

XI. GROWTH 148
Cell-division; nuclear structure; differentiation; repair and regeneration; growth-hormones; metamorphosis; size-limitations.

XII. THE SEED AND THE SOIL 157
Structure of seeds; germination of seeds; soil-structure and its relation to plants.

XIII. AMPHIBIANS (chiefly illustrated by the frog) . 171
Frog-spawn; egg-cleavage; metamorphosis; structure and habits of adult frogs; toads and newts.

CHAPTER PAGE

XIV. SOME LOWLY ANIMALS 181
Amœba; Hydra; Earthworm; Tapeworm.

XV. PECULIAR PLANTS 196
Spirogyra; fungi; bacteria; flowering parasites.

XVI. FRIEND OR FOE? 210
Useful and harmful organisms; control of organisms.

XVII. IRRITABILITY 222
Stimulus and response; nervous systems; plant-responses.

XVIII. PLANT MOVEMENTS 228
Tropisms; response to light, gravity, water; nastic movements in response to light, moisture, dehydration; use in dispersal of fruits and seeds.

XIX. NERVES AND SPECIAL SENSES 237
Nervous tissue; central nervous system of mammals; structure and function of eye and ear; other senses.

XX. FLOWERS 252
Flower-structure; pollination; fertilization; special mechanisms; fruit development and structure; dispersal.

XXI. EXCRETION AND REPRODUCTION IN MAMMALS . 268
Structure and functions of renal system; structure and functions of male and female reproductive system; parental care.

XXII. HEREDITY AND ANCESTRY 274
Methods of scientific investigation; constancy of species; reduction-division; heredity and Mendel; practical value of Mendelism; review of reproduction; origin of species; the evidence of evolution; alternative; mechanism of evolution.

XXIII. INSECTS 289
Structure of an insect (Cockroach); butterflies; house-flies; honey-bees; wasps.

XXIV. FISH, REPTILES AND BIRDS 300
Habits and locomotion; review of vertebrates and their classification.

XXV. COMMUNITIES 310
Pond; aquarium; woods; hedges.

APPENDIX A. NATURE CALENDAR 317

APPENDIX B. EXAMINATION QUESTIONS . . . 320

INDEX 327

INTRODUCTION

To the Teacher:

This book is designed to meet School Certificate (or equivalent) requirements of the established examining bodies in Biology. It should be read in the two years preceding the examination: and it is recommended that the book be read completely twice. For this reason, the questions following each chapter are in two sets. Section A questions, while designed to provoke original thought, are based directly on the material in the chapter. Section B questions are suitable for use after a second reading of the text, as they involve knowledge or experience beyond the scope of the chapter. At the end of the book is a selection of questions from public examinations.

Of the twenty-five chapters, eight are general, eight botanical, and nine zoological. Cross references are plentiful, and while every attempt is made to render the text understandable without them, it is hoped the students will be urged to make full use of them, as this is a great help in integrating their knowledge.

Indispensable technical terms are given in *italics*. Only a meagre knowledge of Physics and Chemistry is assumed.

In this book it is assumed that the reader believes in the existence of God, and accepts the logical consequences of the fact.

To the Student:

No doubt you have read the first part of this Introduction, and little remains but to offer a few hints on how to get the best out of your study of this book.

After reading a chapter, revise it by looking carefully again at all the Figures. Look up in the text any points about the Figures you do not at once understand. If you do not find the answer there, ask.

In your written work, never use a technical term unless you are sure of its spelling and meaning.

In your diagrams, always draw actual specimens when possible, using the text-book only as a guide. Do not hide inaccuracies by "artistic" shading. In most cases, your diagrams should be bigger than those in the book.

When answering questions, do not be content to copy out a piece of the text which seems to bear vaguely on the topic. Give the answer in your own words.

The Index is there to help you. Use it.

ACKNOWLEDGMENTS

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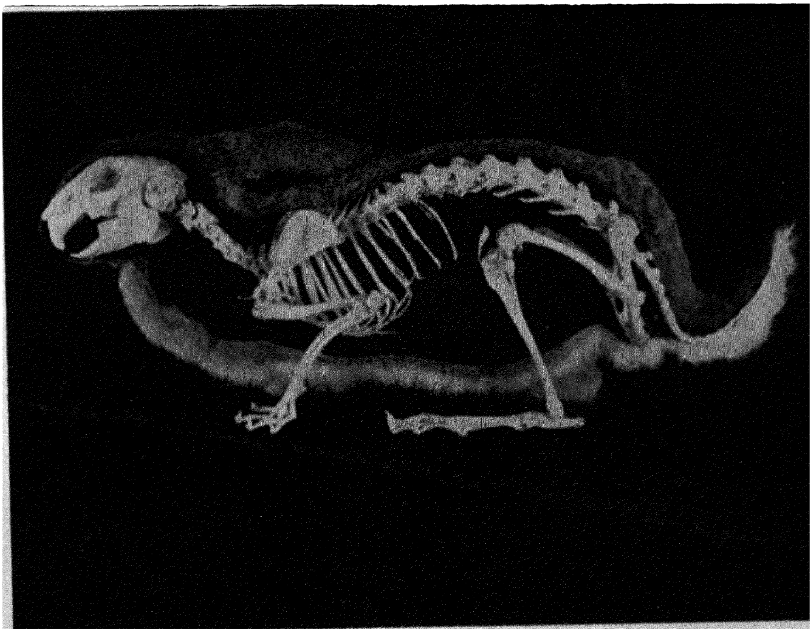
Thanks are also due to the famous firm which owns the original poster on which Fig. 31 is based; to the examining bodies for permission to reproduce questions (see Appendix B); to members of Thornleigh Nature Club, for help in trying out the Inquiries; and not least to the staff of Messrs. John Murray's Educational Department for their advice and co-operation.

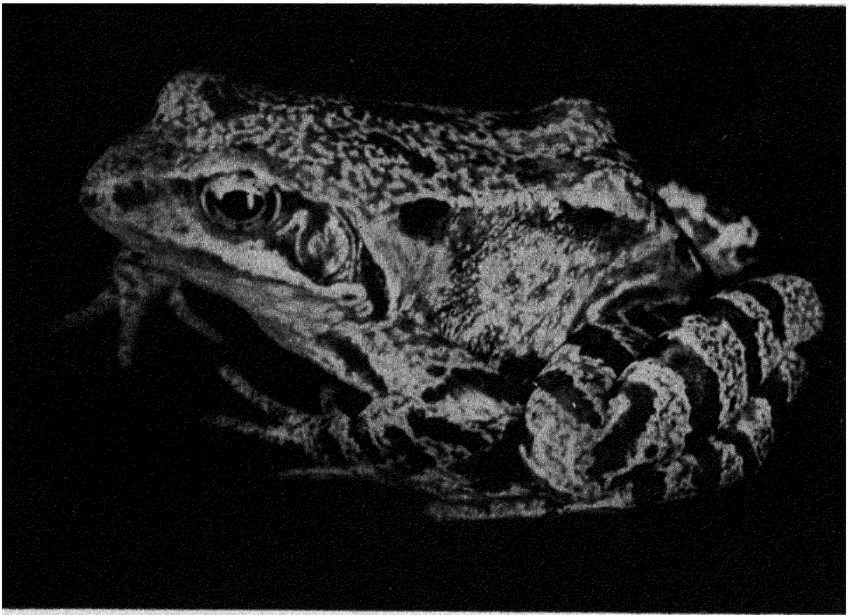
J. G.

RABBIT.

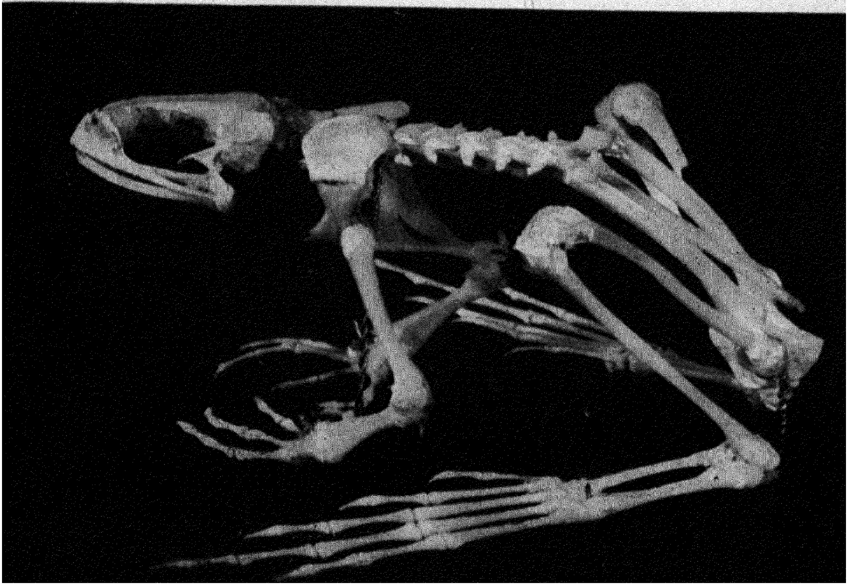


RABBIT SKELETON.

PLATE I.

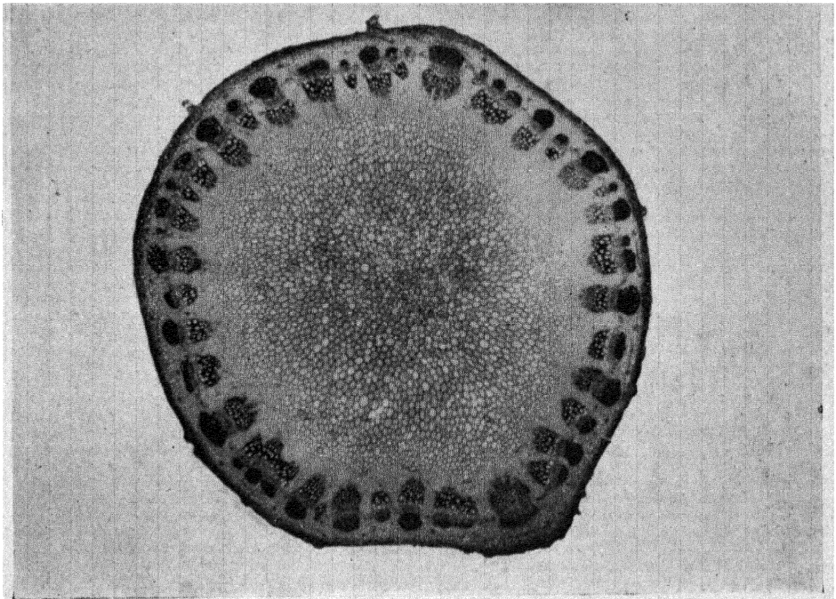


FROG.

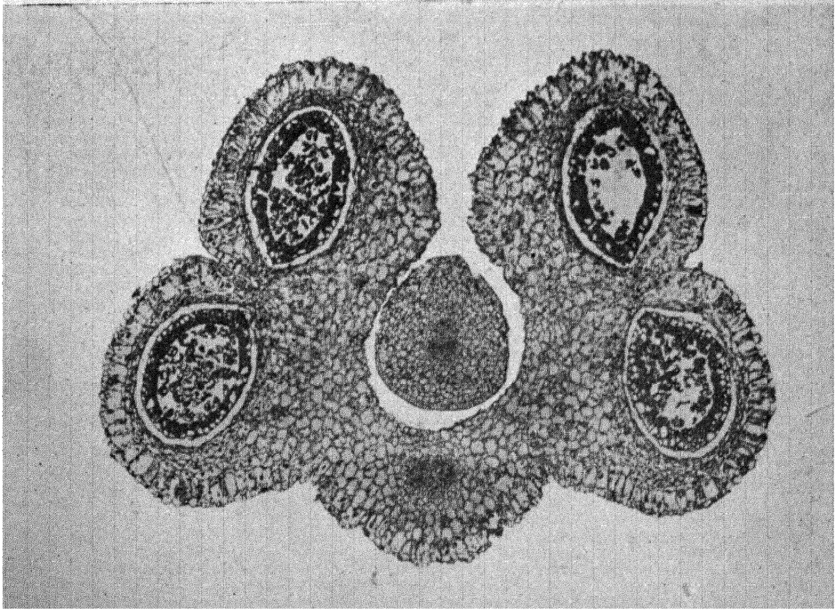


FROG SKELETON.

PLATE II.

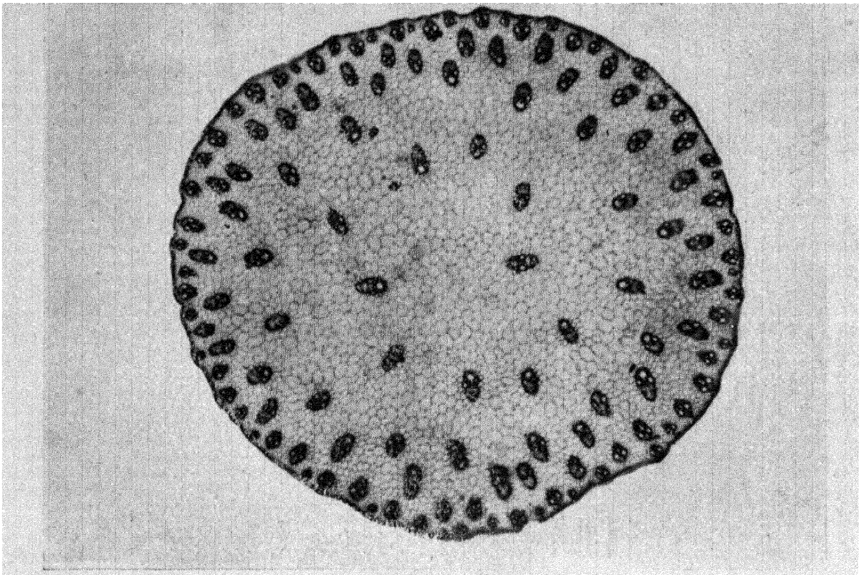


TRANSVERSE SECTION OF DICOTYLEDON STEM (SUNFLOWER) X1

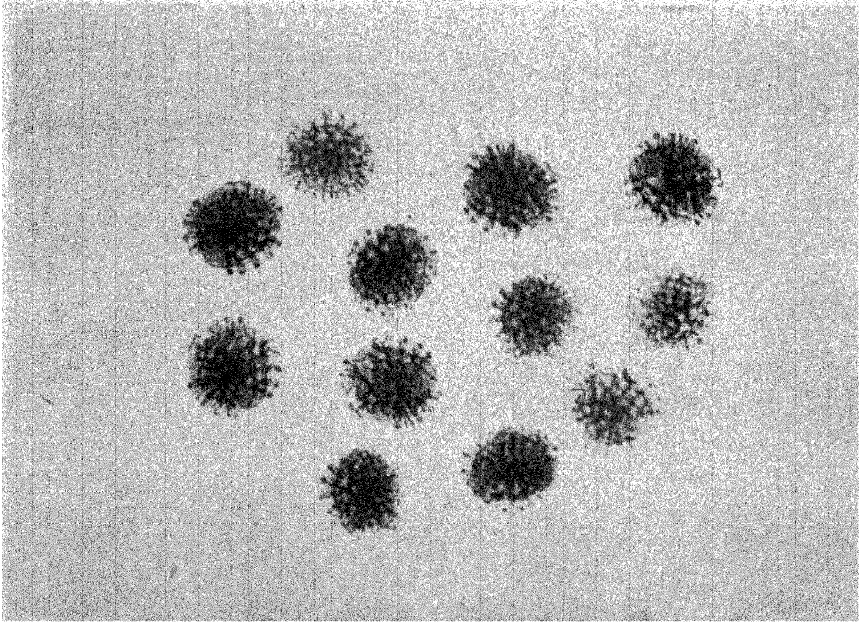


TRANSVERSE SECTION OF ANTHER OF A LILY-FLOWER X25

PLATE III.

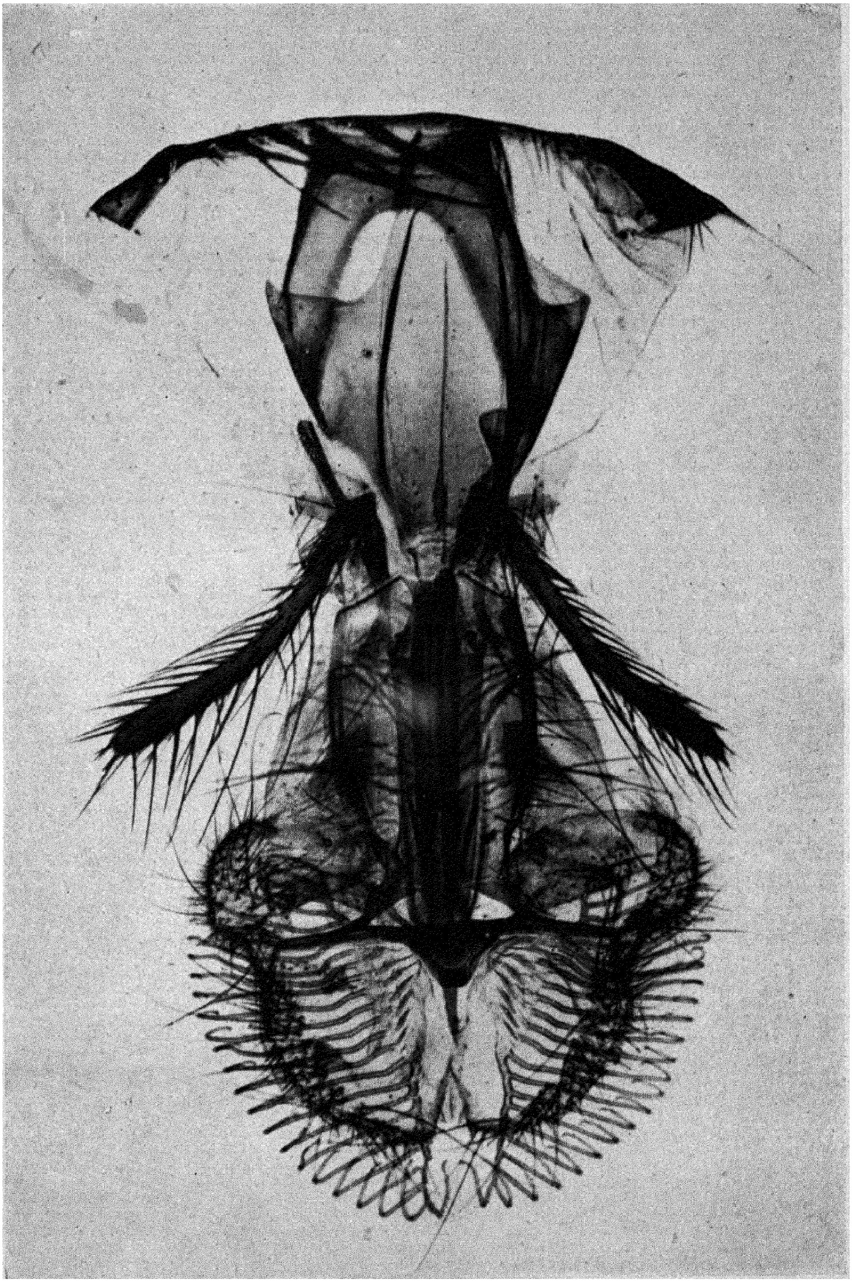


TRANSVERSE SECTION OF MONOCOTYLEDON STEM (MAIZE) X 14



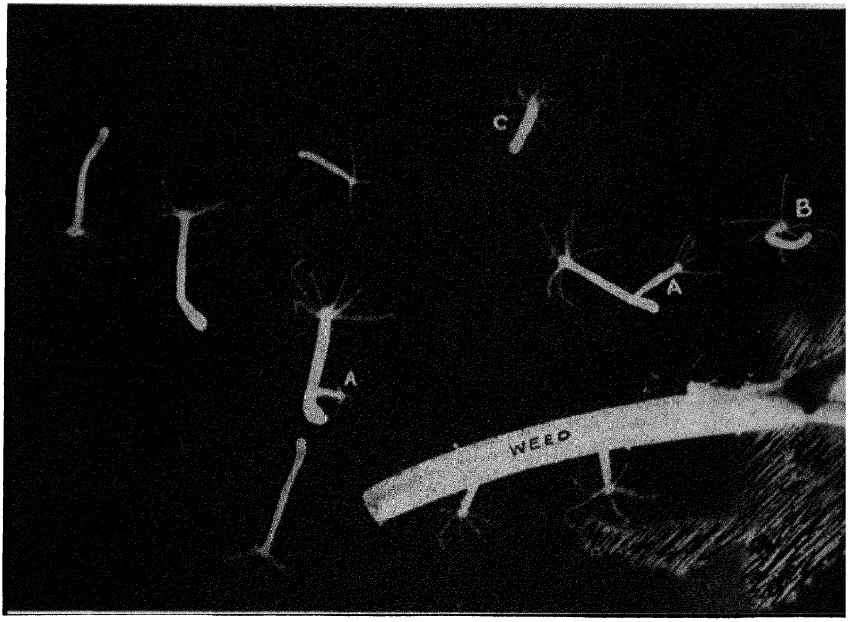
POLLEN-GRAINS MAGNIFIED X 150.

PLATE IV.



PROBOSCIS OF BLOW-FLY HIGHLY MAGNIFIED.

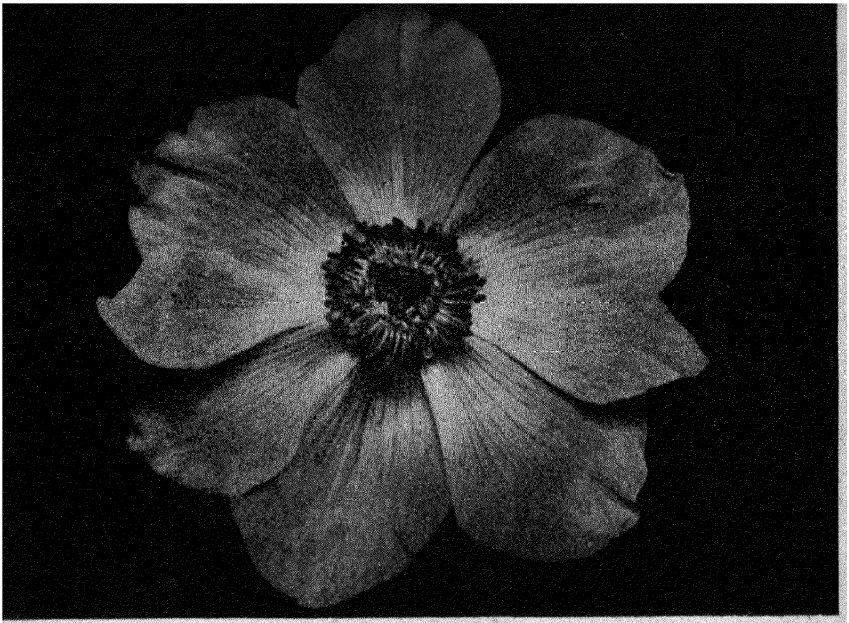
PLATE V.



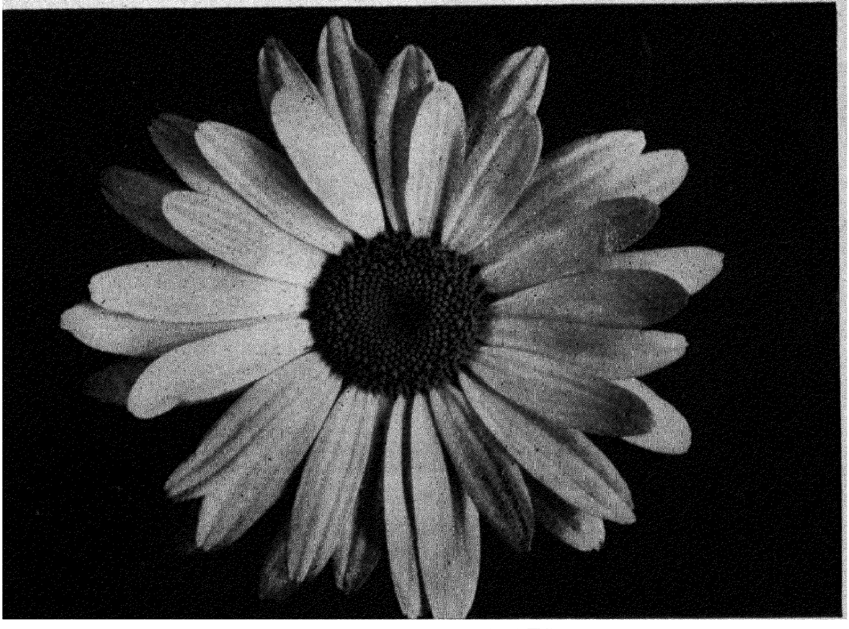
Above: LIVING HYDRA IN POND-WATER.

A.—Buds. *B.*—Hydra looping. *C.*—Hydra contracting.
(The blurred appearance of some of the tentacles shows that they moved while the photograph was being taken.)

PLATE VI.

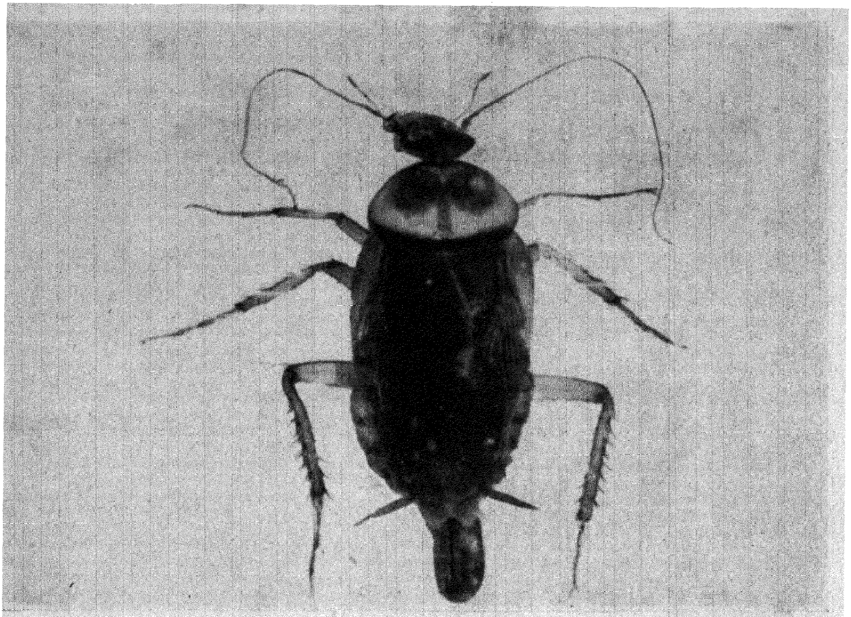


A SIMPLE FLOWER.

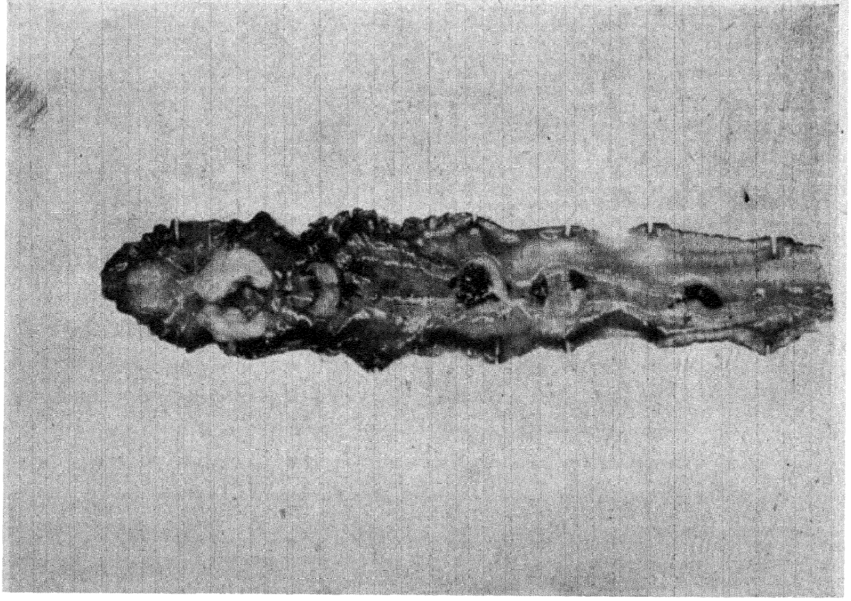


A COMPOSITE FLOWER.

PLATE VII



COCKROACH.



DISSECTED EARTHWORM.

Plate VIII.

CHAPTER I

PREVIEW OF LIFE

At the cinema you must have seen many trailers, showing extracts from next week's film, carefully arranged to make you want to see the whole story. Sometimes they have the opposite effect, but not often. This chapter is a trailer. Since you are already reading the book, it is clear that you are going to study Biology: possibly from choice, but probably because it is just one of the subjects you have to "do" at school. I hope that after reaching the end of this chapter you will carry on at least as much from choice as from necessity.

Why Study Biology?

There are many reasons for studying Biology. From the earliest times, Man's life has often depended on it. The word itself comes from two Greek words and means "the study of life". Throughout history, Man has been observing, controlling and cultivating plants and animals in order to increase his supply of food and make his life more secure. Thus, in the Stone Age, it was very important for men to know the habits of wild animals, so as to defend themselves and obtain food. The Ancient Britons must have known something about herbs, for they extracted a dye from them. These are examples of what may be described as the "bread-and-butter" outlook on Biology.

At the same time, people have always studied living things from curiosity and a thirst for knowledge. One of the first recorded acts of Adam was to find names for the animals.

A knowledge of the wonders of life brings us into contact with much that is beautiful, and increases our respect for its Creator. Christ Himself made much use of people's familiarity with animals and plants in His teaching—think of His references to birds, sheep, wolves, scorpions, lilies, fig-tree, vine, mustard seed. An acquaintance with the abundance and constant renewal of Life reminds us of the colossal maintenance-work required to keep the world of living things working smoothly, a feat perhaps even more wonderful than creation itself.

In modern times it has been found that many diseases of mankind, of crops, and of livestock, are caused by living things, and by studying the habits and life-histories of these we gain more control over diseases. New discoveries are constantly being made in this field: and it is safe to say that Life holds very many more secrets, which may or may not be laid bare in the future; so that there is always something new to seek. As an example, it has only recently been discovered that an insignificant blue-mould can yield a substance (penicillin) which is of great value in the treatment of wounds. That mould has been known for many years, and has been in existence for many thousands of years: its healing-power present all that time, but unsuspected.

It can thus be said that Biology is, at least, not a waste of time.

The World Around Us.

From our earliest days we are surrounded by objects: some living, some not: some visible, some invisible: some necessary if we are to survive, some threatening or attacking us: some which may not seem to affect us in any way. This array of objects, and their activities if they affect us, make up a pattern into which we fit, comfortably or awkwardly. We in turn affect many of the things around us.

This pattern surrounding us is called our *environment* (French: *environs*, neighbourhood). The relations of all the living things in it with each other and with the non-living things around them are called their *reactions* to their environment.

Biology is mainly the study of how living things behave, and why, and the effect their behaviour has on other things around them.

Because it is necessary to recognize a thing before studying it fully, Biology also involves a study of the appearances of living things.

We very soon learn that the reactions between living things are far more complicated than might appear at first.

> INQUIRY 1. Make a list of all the living things you can think of, which have some effect, in one day, on the life of a five-months-old baby.

Did you remember to put down the sheep, the cotton plant, sugar plant, vegetables, rubber plant, as well as the more obvious things? Did you remember the things which must be prevented from having an effect—disease germs, for example? If not, try now to see how each of these factors comes into the picture.

Food-Chains.

The most obvious way in which living things affect each other is in the search for food. As an example, these things are linked together by their feeding: leaves, caterpillars, birds, Man. In some parts of the world, a further link might be added—tiger, for instance. An account of the food-connection between living things is called a *food-chain*, and you will find it interesting, even at this early stage, to work out some examples.

Another well-known connection between living things is in the transmission of disease. It is really a special case of a food-chain. Thus, malaria is caused by a very small animal which normally lives inside a mosquito, feeding on the insect's body-substances, and may be passed into a man's blood if the mosquito bites him. The malaria parasite then feeds on the man's blood, producing poisons which give him a fever. Other examples are tuberculosis of the lungs, caused by a tiny plant called a bacterium, which often reaches Man in the milk from infected cows; and the tapeworm, which passes part of its life in Man and part in a pig.

Living and Non-Living.

We have said a lot about living things, and before going further we must be sure what the term means. "Surely," you say, "everyone knows when a thing is alive?" How do you decide whether a thing is alive? In some cases it is easy. The first thing you would do is almost certainly to "prod" it and see if it "jumps". This is what a kitten does, and is a good rough test; but how would it work on a tree, a man having an operation, or a time-bomb just ready to go off? You see at once that the test is not infallible. In fact, there is no single infallible test, but there is a group of tests, to all of which at some time in its life a living thing may respond. Non-living things may respond to some of these tests, but not to all. Some living things have stages in their lives, during which they respond to only a few of the tests.

The tests are designed to show whether the thing being tested carries out certain activities. There are seven of these activities, and they are called the *primary functions* of living things. They are: *respiration*, *irritability*, *movement*, *nutrition*, *excretion*, *growth*, *and reproduction.*

Respiration is the technical term for breathing, a process which involves, among other things, taking in oxygen and giving out carbon dioxide.

Irritability is the function which we crudely test by prodding. It means that the thing reacts ("does something") when stimulated, by touching it or by other means: and it reacts in a way that cannot be fully accounted for by the slight "push" it receives.

Movement, or better, self-movement (locomotion), means the ability to move without outside power being applied at the time: that is, without being pushed.

Nutrition is feeding: taking in substances and using part of them as a source of energy with which to maintain life, and as materials for growth.

Excretion, a natural consequence of nutrition, is the rejection of substances which, taken in with food, are unnecessary or harmful to the individual, though they may have served a purpose while in the body.

Growth is a steady increase in size or complexity, or both, taking place from within.

Reproduction is the ability of living things, either singly or in pairs, to give rise to other living things of the same kind.

It is clear that most of these functions could be carried out to some extent by non-living things. A motor-car, for example, takes in oxygen from the air, and gives out carbon dioxide from the exhaust; when the accelerator is pressed, the increased movement of the car is much more than can be accounted for by the slight push on the pedal; but it is easy to see that the car does not carry out all the functions, at any time in its existence.

On the other hand, it is seldom possible to observe all the functions going on in one living thing at the same time. Make a list of the ways you think a dried pea- or bean-seed would respond to any tests we could apply for the primary functions, before soaking it in water. Now think what happens when the seeds are planted in warm moist soil, and tended until the plant produces new peas or beans in pods. Here is clear evidence of all except respiration and excretion, just for the trouble of watching: and as you will see later, these two remaining functions are easily demonstrated by simple chemical experiments.

You should note the difference between "dead" and "non-living." A dead thing has once been alive: a non-living thing has not.

Organisms.

Anything which, in the course of its existence, is capable of performing all the above functions, is a living thing, and is called an *organism*. From now on we use this term in place of the two words we have so far been using—"living thing". If you have been thinking carefully it may have occurred to you that many organisms die without ever producing offspring. This is so, and reproduction differs from the other functions; for although every organism is the result of reproduction (an important fact which was shown by Pasteur, less than a hundred years ago, after men had argued about it for centuries), it is not essential for the organism itself to reproduce in order to live. Reproduction is essential, not for the survival of the individual, but for the survival of the race to which it belongs.

Life and Machines.

Our example of the motor-car has shown that machines perform some of the functions of organisms, and it is often helpful, since a machine is simpler than any organism, to describe some functions of an organism as if we were describing a machine.

You must have seen the term "living machine" or something similar, in the newspapers. Do not make the mistake of thinking that the only difference between a machine and an organism is one of complexity. There is a fundamental difference which cannot be overcome by increasing the complexity of the machine, or by imitating the chemical structure of the organism. Some day it may be possible to make protoplasm in the laboratory; but making protoplasm and bringing it to life are two very different things. As yet we cannot make even non-living protoplasm, though we can make rather poor imitations.

Protoplasm.

"Why bring in protoplasm," you say, "and what is it?" *Protoplasm* is the material in all organisms which has the power to carry out the vital functions. It has a very complicated chemical structure and, in addition, the remarkable power referred to above, which distinguishes an organism from inanimate (non-living) matter. In appearance, it is an almost transparent jelly. Chemical analysis does not reveal the nature of its power, since no chemical difference can be observed between living and fresh dead protoplasm. The protoplasm of all organisms is similar, but not identical: indeed, it is probable that no two organisms have identical protoplasm. When one organism eats another it breaks down the protoplasm of its prey into simpler chemicals, and then builds them up into its own kind of protoplasm. The breaking-down process is called *katabolism*, and may be applied not only to the prey, but to the feeding animal's own tissues. The building-up is called *anabolism*, and the whole process is *metabolism*. It combines nutrition, excretion, growth and repair.

Cells.

Protoplasm in organisms is not found in large masses, like jelly in a jelly-mould. It is organized in very small units (hence the term "organism"). These units are called cells, and it is often said that *the cell is the unit of life*. This important fact was first suggested by a priest named Theodor Schwann (1810–82). Most cells are much too small to be seen without a microscope (this explains why it was so long before their existence was discovered) but they are so numerous that together they can form huge bodies such as trees or whales. *A cell is a very small quantity of protoplasm existing as a unit, enclosed by a boundary, and controlled by a structure inside it, called a nucleus.* It may contain various additional substances and structures, and is usually grouped with other similar cells into a larger unit called a tissue. *A tissue is a group of cells working together to carry out a special type of activity.* Tissues are sometimes grouped together within a boundary, and all the tissues within that boundary work in harmony to carry out special tasks. Such a group of tissues is called an *organ.*

Examples of tissues are skin, bone, blood, wood, pith.

Examples of organs are limbs, heart, lungs, leaves, stamens.

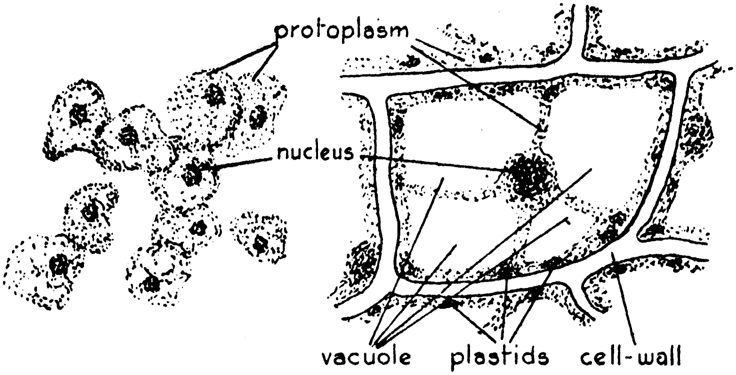


FIG. 1.—Typical Cells.

Cells from inside the human cheek. Cells from an onion scale.

You will meet many types of cells and tissues as you learn more biology, but as this chapter is a preview of life, we may as well peep behind the scenes right away and examine a typical animal-cell and a typical plant-cell. Fig. 1 shows the appearance under the microscope of cells from the inside of the human cheek, and from the skin of one of the fleshy scales of an onion. Remember that the cells themselves have length, breadth and thickness, but the thickness is not obvious under the microscope, and is not shown in the diagrams.

INQUIRY 2. Cells from the cheek are easily (and painlessly) obtained by gently scraping the inside of the cheek once with a clean blunt knife, and placing the scraping with a drop of saliva on a microscope slide. A cover-slip is placed over the drop, which is then examined with a microscope, using low power first, then high power.

The boundary of the cell is itself protoplasmic, forming a thin skin, rather like the skin on a cooling drop of molten wax. Its biggest diameter is about one-fiftieth of a millimetre, or less than one-thousandth of an inch. Inside the cell is the nucleus, a speck of protoplasm denser, and therefore darker, than the rest, and believed to be the controlling body or "headquarters" of the cell.

INQUIRY 3. The onion-cell is obtained by cutting the surface of one fleshy layer of an onion, gently tearing off a scrap with fine forceps, and placing it in a drop of water on a slide.

An important difference from the other cell is seen at once—the onion-cell, like nearly all plant-cells, is enclosed by walls as though it were in a box. These walls are made of *cellulose*, and are formed by the cell. Cellulose is not alive: it is the material we know as paper, cotton, artificial silk, and under many other names.

The nucleus of the cell will be easier to see if a drop of weak iodine solution is placed at the edge of the cover-slip, and drawn under it by placing a strip of filter-paper at the opposite edge.

Another point to notice is that the plant-cell is not filled with protoplasm, but only lined with it, a few extra strands stretching across the central space to the nucleus. This central space is called the *vacuole* and is filled with *cell-sap* (a very weak solution of salts).

Embedded in the protoplasm lining the cell-walls are small bodies which are very difficult to see in the onion-cell because they are colourless. They are called *plastids*. In green plant-cells all the green colouring is in the plastids, which are then called *chloroplasts* (Greek: green, moulded objects).

You may be surprised at our choice of a human-cell as a typical animal-cell. Man has the characteristics of animals, so is included with them. The alternative, to include Man among the plants, would be even less complimentary, as well as less scientific. The chief thing which distinguishes Man from other animals is his soul, which has a *supernatural* life (Latin: beyond the natural), and so does not come entirely within the scope of biology, or, as it used to be called, "*nature*-study". It is, however, the most important characteristic of Man, and therefore has great effects on his animal characteristics. For this reason it must be kept in mind even when we are studying Man simply as an animal.

Plants and Animals.

Every organism in the world is either a plant or an animal, and we are now able to consider how plants differ from animals. Sometimes it is easy to decide to which group a given organism belongs, but sometimes it is very difficult, and then the most reliable test is usually the method of nutrition. *Plants are able to make protoplasm from very simple chemicals* such as carbon dioxide, water, and potassium nitrate and other salts. *Animals must start with much more complicated substances*, such as protoplasm from another organism, or sugar, fat and protein. You can see now why *animals cannot live without plants*; they need the plants to build up chemicals into complex substances which form the food of animals. This is summed up in the saying: "All flesh is grass."

This difference in nutrition is the most important distinction between plants and animals, but once again there is no single infallible test, and we have to rely on other facts as well. Here is a list of the main points in which plants differ from animals:

Most plants show less irritability than animals.

Plants are usually less mobile than animals.

The nutrition of plants is usually less obvious than that of animals.

The same applies to excretion, and for the same reason, namely that substances involved in these two processes are usually gases or colourless liquids in the case of plants, less often so in animals.

Plant-cells normally have cellulose walls; animals never make cellulose.

Some cells of most plants contain *chlorophyll* (Greek: green stuff in leaves); animal-cells never contain it.

You will see at once there are many exceptions to these points, and as you learn more biology you will meet many more. Here are some examples: many sea anemones look like flowers, and spend most of their time fixed in one spot: yet they are animals. Many very small plants swim about in water during most of their lives. Mushrooms and fungi are plants which cannot make their own food, but have to absorb it ready-made. The reproductive cells of many plants do not possess cellulose walls. Some animals seem to contain chlorophyll, because they have small one-celled plants inside them.

Names of Organisms.

It is obviously not enough to say that a particular organism is a plant or an animal, and leave it at that. "Animal" might refer to a one-celled amœba or an alligator, a hen or a hippopotamus. It was stated on page 1 that one of the first things Adam did in the Garden of Eden was to name the creatures he found there; and this habit seems to be implanted in all of us. A very young child has names for things, which no one else can understand, and this is not very useful. The usefulness of a name is greatest when it means the same thing to most people. In a small community, especially in olden times when travel was difficult, it was often enough to give a person a single name: we have heard of Boadicea or Caractacus, Hengist and Horsa, or similar names. When people began to travel, it was found that many people had the same name, and to avoid confusion it became customary to give everyone two names, one of them his own personal name, and the other describing the family or village or trade to which he belonged. Now, although many people might have the same first name, and many others the same second name, it was less likely that many people would have the same two names. It does happen, of course, and we still meet examples of John Smith Senior and John Smith Junior, or even Old John and Young John.

In the case of plants and animals, it is unnecessary and even impossible to give a different name to every individual; so we give the same name to all those individuals which are so much alike, that close inspection would save us from mistaking them for others, which resemble them in some ways, but not in all. This we call the *species* name. Then all those species which closely resemble each other are given another name. This is called the *general* name, and the group is called a *genus* (Latin: kind or sort). Thus every organism has at least two names. The genus name is usually placed first. Latin words are used for these names, so that scientists everywhere will know exactly which animal or plant they refer to when they use them.

Thus the cabbage, which has a different name in every language, is known to all botanists as Brassica oleracea. The turnip belongs to the same genus, Brassica, but to a different species, Brassica campestris. Notice that the species name is not given a capital letter.

This system of naming or *classifying* organisms was worked out in detail by a famous Swedish biologist, Linnaeus, in the eighteenth century. It does not stop at the general stage. Genera are collected into bigger groups, and these again into still bigger ones, until finally we reach the two *kingdoms*, Plants and Animals, forming a single group, *Organisms*, which covers all the living things in the world. The names of the intermediate groups are rather different for plants than for animals, and at this stage we can afford to consider only a simplified version of the scheme.

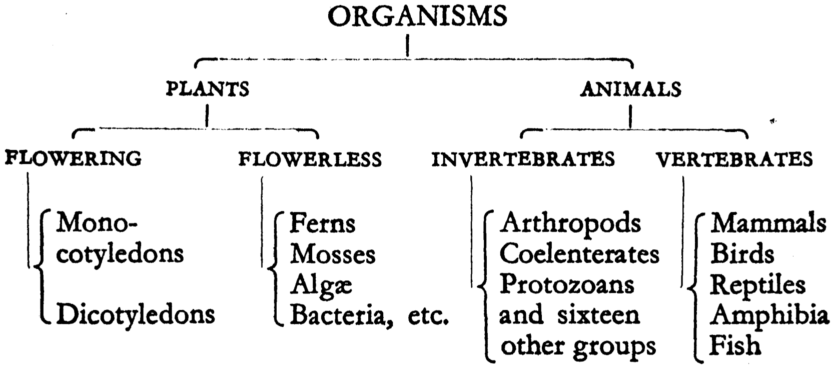
Classification of Animals.

Starting with the biggest groups, we divide all animals into two sub-kingdoms, those with backbones and those without. We call these *Vertebrates* and *Invertebrates* respectively. The vertebrates are divided into five classes: *Fish*, *Amphibia*, *Reptiles*, *Birds and Mammals*. In later chapters we shall see how to decide to which class any given vertebrate belongs. The invertebrates are divided into nineteen smaller groups, of which these are some examples: Arthropods (lobsters, spiders, insects, etc.); Molluscs (mussels, snails, etc.); Coelenterates (jellyfish, etc.); and Protozoa (one-celled animals such as amœba).

Classification of Plants.

All plants are either *Flowering* or *Non-Flowering.* The flowering plants are divided into two groups, Monocotyledons and Dicotyledons. We shall see the meaning of this later (page 157). Non-flowering plants include horsetails, ferns, mosses, algæ, bacteria and many others.

Having made in this chapter a rapid and rather sketchy survey of the world of living things, we can now go on to take a closer look at some of them, and so obtain a slight idea of the astonishing ingenuity and power required to create and maintain in existence the wonderful thing which we so often dismiss with a shrug of the shoulders: "That's Life."



QUESTIONS

SECTION A.

1. Name three living and three non-living things which are important factors in your environment. Choose one of them, and say briefly what effects its removal would have on your mode of life.

2. Name five organisms which would form part of the environment of a domestic cat, and describe its relations with two of them.

3. Describe the ways in which a motor-car resembles an organism, and explain clearly why it cannot be described as alive.

4. Write short notes on protoplasm, vacuole, cell-sap, plastid, cell-wall.

5. Make a list of at least six substances in common use, apart from food, which are obtained from organisms, and state the source of each.
6. Compare the structure of a typical plant-cell with that of a typical animal-cell.
7. Write a short essay (150 words) on the value of classification.
8. Explain clearly why it would be incorrect to describe a fire as an organism.

SECTION B.

1. Plants are usually less mobile than animals. Why is this, and what disadvantages does it involve for the plants?
2. Take each of the primary functions in turn (except reproduction) and try to name two examples of non-living things which perform it. In each case give reasons for deciding that the object is not an organism.
3. Construct a food-chain ending in a seagull.
4. Name one example of each of the following groups of organisms, and state in each case why you would place it in that group. Mammal, reptile, coelenterate, monocotyledon.

CHAPTER II

GREEN FLOWERING PLANTS

In ordinary conversation, when speaking of "plants", we usually mean green flowering plants: and this chapter deals with their general appearance, and its relation to the way they live and work.

Herbaceous Plants.

The term *herbaceous*, which is applied to these plants to distinguish them from the other flowering plants (shrubs and trees), means that the plants are, in a very general way, either grass-plants or similar to them (Latin: *herba*, grass). In practice, it includes many plants whose similarity to grass-plants is extremely slight.

In order to qualify as herbaceous, it is necessary only that the plant should be a flowering plant whose parts above ground live for only one year. Even if the plant comes up in the same place every year it must have a complete new set of parts above soil-level. These parts together form the *shoot*, and the parts below ground form the *root*. A few types of shoot and root form exceptions to this general rule, but we shall discuss them at a later stage (page 102).

Roots.

If you have never seen the underground parts of a plant, you would still have some idea what they were like, because common sense tells us that they must be fitted to do certain things for the plant. They must, for instance, support the weight of the shoot in a normal plant, and anchor the plant in the soil: and since it is common knowledge that plants kept in pots have to be watered, it is reasonable to suppose that the roots absorb water from the soil.

> INQUIRY 4. Examine the roots of cress-seedlings obtained as follows: Pour water into a small plant-pot and rinse it round. Empty the surplus water, and scatter cress-seeds round the inside of the pot. Invert it in a saucer of water, plug the hole with cotton-wool, and leave in a warm place for three or four days. The seeds will be found to have *germinated*, that is, each will show a pale greeny-yellow shoot growing upwards, and a white thread-like root growing downwards.

Notice first that the shoot and root grow in the right directions, no matter how the seed lay at first. If necessary, they will turn through a half-circle in order to achieve this. The importance of this fact is dealt with more fully in Chapter XVIII; just now we need only note that it results in the parts of the plant reaching their proper surroundings, when the seed germinates in the ground.

A hand-lens will show that the root is not just a single thread with a smooth surface, but has a number of very fine hairs growing from it for part of its length. They are absent from the tip of the root, and from the part nearest the shoot.

These *root-hairs* are very important to the plant, for it is they, and not the main root-thread, which really absorb the water and salts needed by the plant. In the soil, each root-hair presses tightly between the soil-particles, so that it is bathed in the film of moisture which surrounds them. Each hair is an outgrowth from a single cell on the surface of the root. The part of the root where the root-hairs grow is called the *piliferous* (Latin: hairy) *region*. In Chapter VI we shall examine how the work of absorption is carried on.

The delicacy of the root-hairs explains why, when a plant is pulled out of the soil for transplanting, it sometimes fails to recover, although it has not been visibly damaged. Plants for replanting should always be removed with plenty of soil sticking to the roots, and replanted without shaking it off.

The part of the root between the piliferous region and the tip is continually increasing in length and forcing its way through the soil. This explains why it bears no root-hairs: they would be sheared off as it grew. As each further section of the thread becomes established in the soil, root-hairs develop on it, and later die away as new ones appear lower down.

The main thread of the root, which, as the plant grows, becomes thicker and produces *lateral* (side) branches, provides the plant's *anchorage and support*. The course of further development varies a good deal. In most dicotyledons (page 157), the root-thread grows thick and strong, and is then called a tap-root. The carrot is an extreme example, but the dandelion also shows it quite well.

> INQUIRY 5. Loosen the soil round a small dandelion plant with a gardening fork; then grasp the complete shoot, and pull it slowly but firmly straight up from the soil. This will break off the root-hairs and most of the root-branches, but the long *tapering* tap-root will be intact.

In trees, which are also dicotyledons, the lateral roots go on branching until the tap-root is lost in the tangle. This gives the tree a wide area of support, called the *root-platform*.

Monocotyledons also develop a much-branched root system, but in this case the roots grow out, not from the tap-root, which soon withers, but from the base of the stem. They are therefore called *adventitious* (out-of-place) roots. They form a *fibrous root system*.

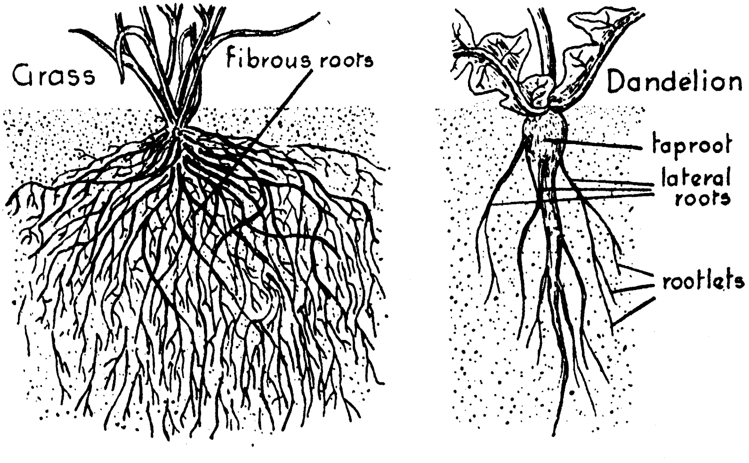


FIG. 2.—Typical roots.

INQUIRY 6. Loosen the soil round a small tuft of grass and gently ease it out of the ground. Leave it to dry until most of the soil can be easily shaken off, and examine the roots. Note the tangled mass of fibres, and the way the soil clings near the end of each fibre, in the region of the root-hairs, while it can be easily removed from the tips and older parts of the roots.

The size of the root system bears some relation to the size of the shoot. If the shoot is in favourable surroundings, the root will be stimulated to further growth; if the root system is cramped by lack of soil or hardness of ground, the shoot will obtain less water and salts. Thus the whole plant adjusts its size to its environment.

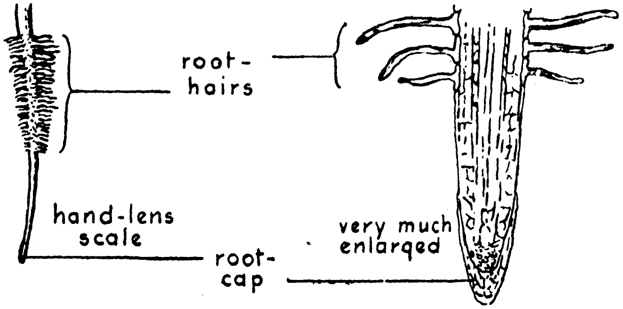


FIG. 3.—Root of cress-seedling.

Except in the region of the root-hairs, the root has a waterproof surface to prevent water from escaping after being absorbed. This surface is a skin of cork-like material. Branches arise underneath this layer, and force their way through it when they are strong enough. The tip of each root-branch, and of the main root, is covered with a cap of protective cells to prevent injury as it forces its way through the soil (Fig. 3).

Later in this chapter we consider the internal structure of the root, and in Chapter VII are described some of the ways in which the root may be modified for special purposes. On page 37, roots are compared and contrasted with shoots.

Shoots.

There is very much more variety of form in shoots than in roots, so it is not easy to make general statements about them;

but there are some features which are common to all shoots, and we shall consider these first.

Stem and Leaves.

It may be said that the stem of a plant exists mainly to support the leaves: for the leaves (and, in season, the flowers) are the most active parts of the plant. In order to work well, they must be placed in correct relation to air and sunlight: they must be provided with water and salts: and most of the food made by the leaves must be carried away and stored.

These functions are carried out by the stem, and its structure enables it to serve all these needs efficiently.

Erect Habit.

In most herbaceous plants the stem grows almost vertically, and thus the stem is said to have an *erect habit*. The word "habit" is used in Botany (plant-study) in a rather special sense, meaning "general appearance". In Zoology (study of animals) it keeps its more common meaning of "customary activities".

The stem, which is usually slender, is *stiffened* in several ways to help it to keep up the erect habit. It may be cylindrical or many-sided, solid or hollow, but the strongest tissues are always near the surface, in contrast with the root (page 23), where they run down the centre. These two arrangements correspond to the different forces which the shoot and the root have to withstand. The shoot carries the weight of leaves and fruit, rain and snow, and is blown by the wind. These are all "crushing" forces; the root, on the other hand, is more likely to be *pulled* than crushed, as the stem bends, or is plucked by animals.

> INQUIRY 7. Take two sheets of foolscap paper. Roll one into a long cylinder about an inch in diameter, and slip a rubber band round it. Stand it on a level surface and pile books on it until it shows signs of collapse. Roll the other piece more tightly into a "stick" and lightly support it in a vertical position while your partner puts on it the same pile of books. It will not support them.

Remember, too, that a tow-rope, which withstands a pulling force, is thin and solid, while a pillar, withstanding crushing force, is wide and often hollow.

Secondly, the inner cells tend to grow longer than the outer ones: being enclosed they do not succeed, and the strain set up helps to keep the stem erect.

> INQUIRY 8. Cut the ends of a stick of rhubarb squarely and peel off the skin. As the strips of skin come off they curl up outwards, because their inner cells, being released, stretch to their full length. If the stem of a dandelion flower is split, the cut surfaces curl away from each other for the same reason.

Arrangement of Leaves.

The arrangement and spacing of leaves on a stem is not haphazard. There is always a plan, which may be simple or complicated, but it always results in the leaves and flowers appearing in just the positions where they can be most effective. In the mint (Fig. 4), one arrangement common in dicotyledons is shown. The leaves arise in pairs, on opposite sides of the stem, and each pair is roughly at right-angles to the pairs above and below it. Thus the leaves do not overshadow each other and the stem is well balanced.

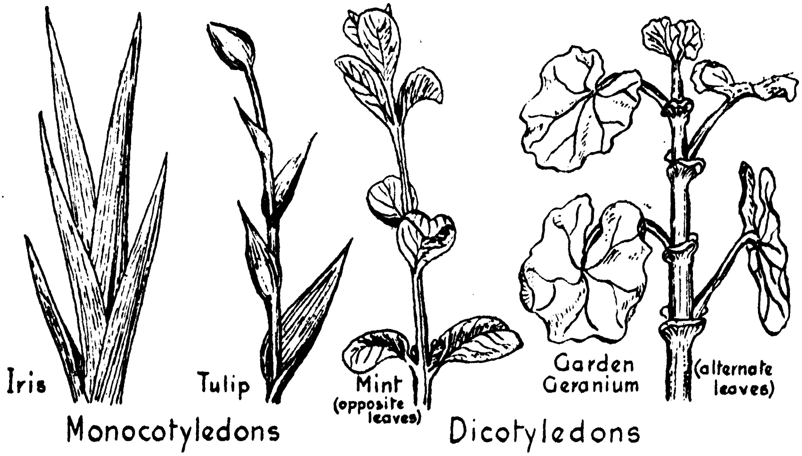


FIG. 4.—Typical leaf-arrangements.

We shall return to this topic when discussing tree-stems (page 43).

Position of Branch.

The branches of a stem, whether leafy branches or flowering branches, arise from *buds on the surface* of the stem. A bud may be terminal or lateral (Latin: *terminus*, end; *latus*, side). *A terminal bud occurs at the end of the main stem or of a branch. A lateral bud occurs at the side* of the stem or branch, and since it always arises in the corner or *axil* between a leaf and the stem, it is often called an *axillary bud.* A flowering branch is called an *inflorescence.*

Structure of Buds.

Buds are of two types, *summer buds* and winter buds. The latter are described in the next chapter, as they are found chiefly on shrubs and trees. As an example of a summer bud, the *Brussels Sprout* is very convenient because of its large size. Fig. 5 shows its appearance when cut in halves lengthwise. It contains in miniature all the parts of the shoot into which it will grow. A cabbage is a giant bud.

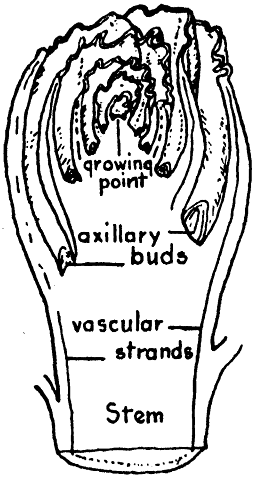


FIG. 5.—Section of a summer bud (Brussels Sprout).

Modified Stems.

In some plants, such as the *Daisy*, the stem is so short that the leaves form a *rosette* close to the ground.

There are many plants whose stems are not strong enough to support the weight of the leaves and flowers. In such cases the stem is modified in some way which enables it to obtain extra support. In the *Wall-Ivy*, for instance (Fig. 6), roots grow out from the stem at intervals, and serve to attach it to a wall or other support. These are adventitious (out-of-place) roots.

The *Greater Bindweed* (Convolvulus), a plant commonly found in hedges, with beautiful trumpet-shaped flowers, has a thin stem which *twines* round the firmer stems of other plants, and so carries its leaves into positions where they can obtain fresh air and light.

Some plants have *creeping stems*. The *Ground-Ivy* is a good example: and in Chapter VII we shall meet other examples, where the creeping habit is made use of in reproduction.

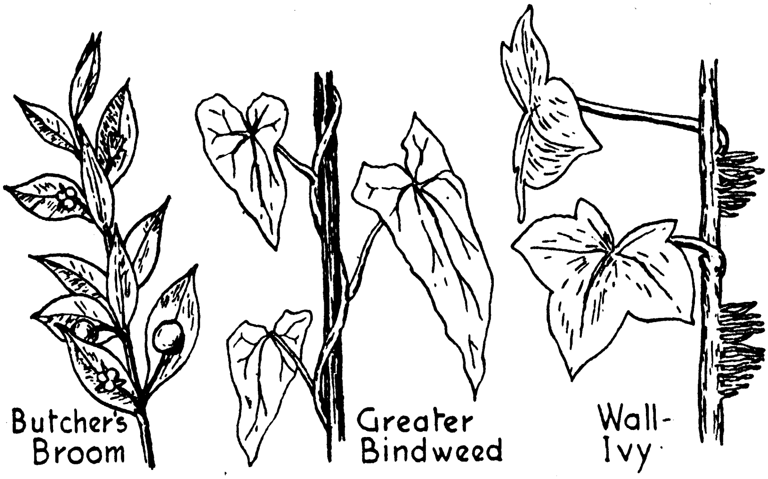


Fig. 6.—Modified stems.

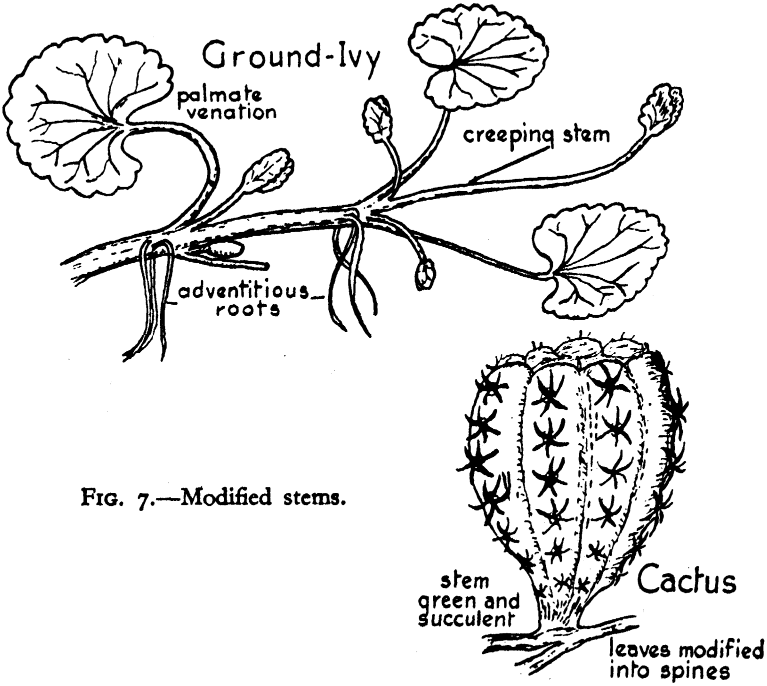


Fig. 7.—Modified stems.

In a few plants the stem takes on work which normally belongs to the leaves. In the *Butcher's Broom*, the leaves are reduced to insignificant scales, while the branches are leaf-like both in shape and function. A shoot which is leaf-like is called a *cladode.*

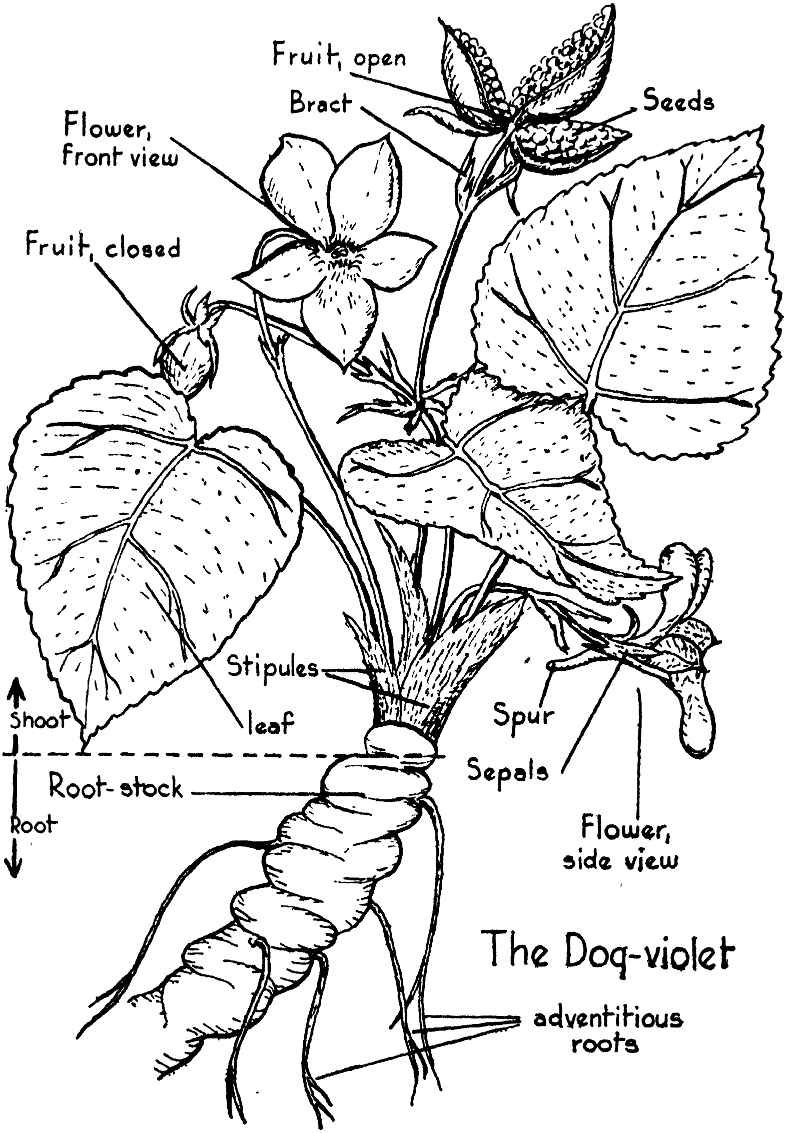


FIG. 8.—A complete flowering plant.

The *Asparagus* also has cladodes. In the *Cactus*, the whole of the green part of the plant is stem, while the leaves are in the form of prickles. The swollen stem is *succulent* (juicy).

The stems of many herbaceous plants have spines or hairs on them, which make them less palatable to animals, or prevent insects from climbing up to nibble the tender shoot-tips.

Internal Structure of Root and Stem.

Although at this stage we are only required to understand the internal structure of roots and stems in such detail as can be seen with a hand-lens, it is useful to examine the microscopic appearance, as this helps us to interpret what the hand-lens reveals. The following description of internal structure applies only to dicotyledons (Plate III).

There is more than one kind of tissue inside the root and stem (Fig. 9). In both, the greater part of the tissue is made up of cells very much like the typical plant-cell we considered in Chapter I. Such unmodified cells are called *ground-tissue* or *parenchyma* (Greek: packing). Passing through this are strands of specially modified cells which carry out special functions.

In the root these special tissues are all found in a central group called the *stele* (Greek: a post). The central cells of the stele form a tissue called *xylem* (Greek: wood), consisting mainly of long tubes formed from cylindrical cells placed end to end. Their end-walls have decayed, providing a continuous path for the passage of water and salts up into the shoot. The living contents of the cells have disappeared, after depositing in the remaining walls a substance called *lignin* (Latin: wood), which turns them into *wood*. Among these tubes are a number of *fibres*, also lignified; so the xylem in the root of even a herbaceous plant is strong *woody tissue*.

The xylem-strand increases in thickness by the addition of new vessels formed by a ring of special tissue called *cambium*. This consists of simple brick-shaped cells, which are continually dividing into pairs of cells, one of which forms a new xylem-cell, and the other develops into a cell which forms part of the other type of tissue found in the stele, namely the *phloem*.

Phloem (pronounced flo-em), also called *bast*, consists of conducting tubes: but in this case the cells remain alive, and their end-walls, instead of decaying, simply become perforated like sieves. The resulting tubes are therefore called *sieve-tubes*. Each sieve-tube has a row of cells along its outer surface, called

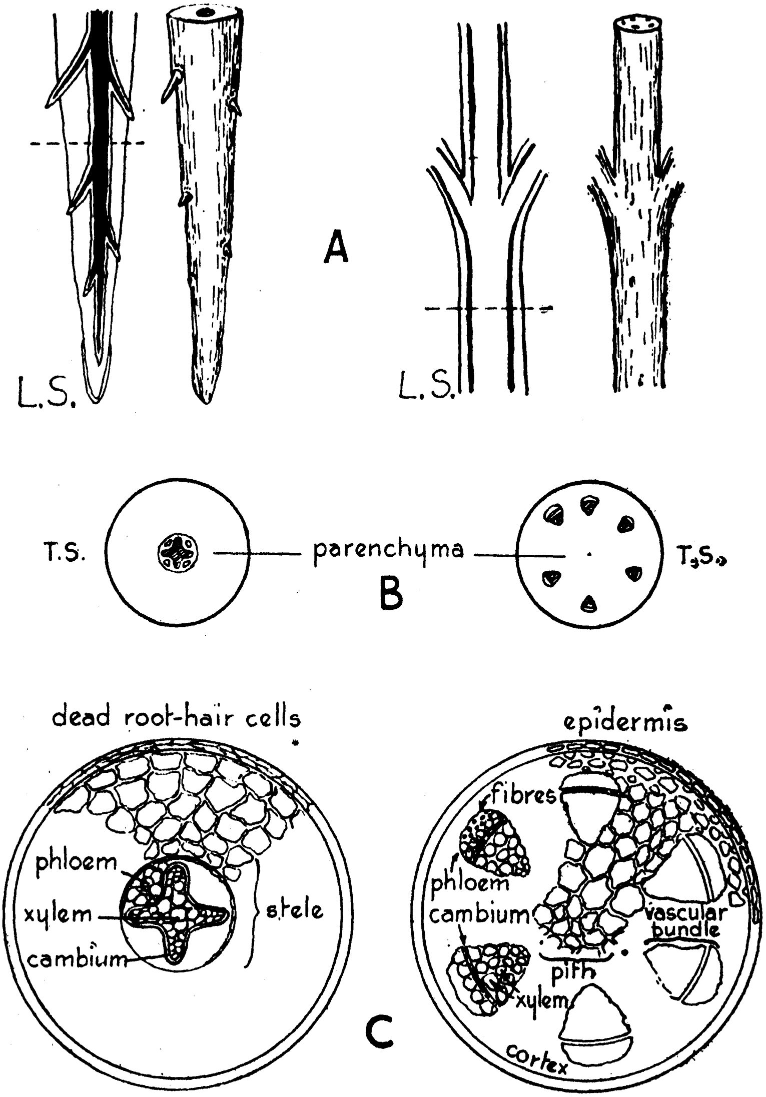


FIG. 9.—Internal structure of root and stem.

the companion-cells. The phloem is believed to transport sugar and other foodstuffs up and down the plant.

Since the cambium gives rise to both xylem and phloem, it must be placed between them. The resulting arrangement is seen in Fig. 9, B and C.

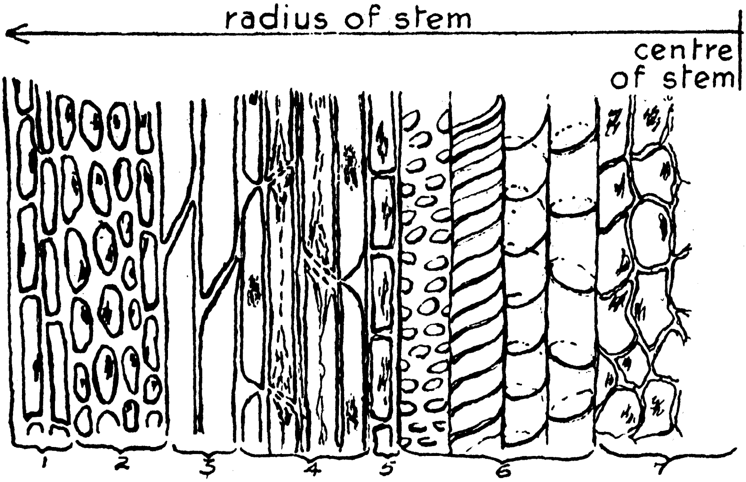


FIG. 10.—L.S. (diagrammatic) of stem of a dicotyledon (e.g. Sunflower). 1. Epidermis. 2. Cortex. 3. Fibres. 4. Phloem. 5. Cambium. 6. Xylem. 7. Parenchyma (pith).

In the shoot, the same tissues are represented, but instead of being concentrated at the centre they are split up into bundles and distributed round the circumference of the stem. The reason for this has been seen on page 18. Each bundle is called a *vascular* (vessel) bundle, and contains xylem, phloem and cambium. In addition, it often has an extra strand of woody fibres at its outer edge. These are called the *pericycle fibres*, and play a big part in keeping the stem erect. The general arrangement is seen in Fig. 9, B and C. The ground-tissue within the ring of vascular bundles is called the pith, and that between them and the surface (epidermis) of the stem is called the cortex. The cells near the epidermis usually contain chloroplasts, giving the stem a green colour. The epidermal cells have thick outer walls containing a waterproof substance (cutein). They are said to be *cutinized*.

INQUIRY 9. Examine with a hand-lens pieces of the root of a bean-seedling cut as in Fig. 9. The upper diagram on the left shows a root cut down the centre. This is called a *longitudinal section* (usually abbreviated to L.S.). The lower diagram shows a section made by cutting exactly at right-angles to the length of the root, and is called a transverse section (T.S.). The two views which result from these two types of section are very much used in biology, and you should take care to understand what they represent.

In the bean, the stele is easily recognized, and its wood can be made much more obvious by dipping the section in aniline chloride solution, which in a few minutes stains the wood-cells bright yellow, the phloem slightly brown, and leaves the parenchyma colourless.

Stain your sections as described above and make diagrams of them.

INQUIRY 10. Carry out a similar examination of pieces of sunflower stem, and compare your drawings with those of the bean-root.

Secondary Tissues.

The tissues considered so far are called *primary tissues*, because they develop during the first year of a plant's growth. Many plants live for several years. If they are herbaceous, there is a new shoot system every year, each with its own primary tissues; but the root may persist for several years, and as it grows older and thicker new tissues are produced to cope with its development. These are called secondary tissues, and are described in the next chapter, dealing with shrubs and trees, which develop secondary tissues in the shoot as well as in the root.

Annuals, Biennials, Perennials.

A plant which completes its life-cycle in one year is called an *annual.* It grows from a seed, forms a fully-grown flowering individual, produces new seeds, and dies, all in one year.

Some plants do not produce flowers until their second year. Most of them spend the first year in developing into a sturdy plant with plenty of food reserves. As a result, these plants have been greatly developed by Man as food-crops, and in such cases the plants are not usually allowed their second year of life. Plants whose life-cycle occupies two years are called *biennials*. Carrots, radishes and foxgloves are examples.

Perennial plants are those which survive for several years, either by growing a new shoot each year or by having a woody shoot. The majority of flowering plants in Britain are perennials.

The Leaf.

Though all parts of a plant are necessary if it is to develop fully, the leaves are in many ways the most important organs, because in most plants it is the leaves which provide the bulk of the plant's food and control its life-processes.

Leaf-Shape.

It is impossible to sum up all the varieties of leaf-shape in a simple statement, but it can be said that most leaves are flat, thin, green, and attached to the stem by a stalk. There are exceptions to each of these features.

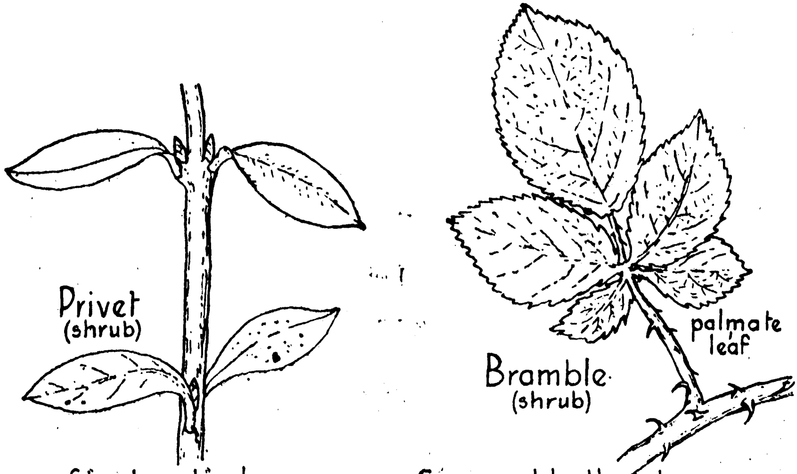
The flat part of a leaf is called the *blade* or lamina, and the stalk is called the petiole, from a Latin word meaning "little foot".

A vascular strand passes from the stem, through the petiole, and into the blade, where it usually continues as a *midrib*. An irregular *network* of branching veins may arise from the midrib and spread all over the blade. *Net-veined* leaves are the rule in dicotyledon plants. In monocotyledons, the veins all come off the midrib as it enters the blade, and run *parallel* to it along the leaf. These two arrangements are seen in Fig. 4.

Usually the veins are more easily seen on the *underside* of the leaf, which is often a paler green than the upper surface. If the leaf grows vertically, as in the iris and daffodil, it has no underside, and both sides are alike in appearance and in internal structure.

The stalk enables the leaf to turn and present its upper side to the sun, and protect its underside. It also allows the leaf to sway in the wind without being injured. If both sides of the leaf are alike it seldom has a stalk. Thus it is less flexible and requires greater mechanical strength; this it obtains by becoming thicker than is usual in a stalked leaf. In spite of this, iris and daffodil leaves often break.

When we examine a leaf with a microscope we shall discover that the *pores* (stomata, plural of stoma, Greek word for mouth), through which gases enter and leave the leaf, are nearly all on the underside. This explains one fact which is easily observed without a microscope, namely that the underside of a leaf is usually more hairy than the upper surface. These hairs trap a layer of air and keep it fairly still, so that the gas-exchange can go on smoothly. This layer of air also protects the leaf from sudden changes of temperature by acting as a blanket. The degree of hairiness of leaves varies enormously from plant to plant, some being quite downy while others have a highly-polished upper surface.



Simple entire leaves — Compound toothed leaves

FIG. 11.—Leaf-shape.

The outline of the leaf-blade takes many forms in different plants, but is usually remarkably constant for any particular species, so that a single leaf is often enough to identify a plant (Fig. 25).

When the stalk leads to a single blade, as in the privet or the oak, the leaf is *simple*. If the stalk bears several distinct *leaflets* which could be removed without tearing, the leaf is *compound*. Every leaf belongs to one or other of these classes.

The edge of the leaf or leaflet may be smooth (*entire*). If not, it may be *toothed* (bramble), or *wavy* (oak), or more deeply divided into *lobes*. If these lobes make it vaguely like a hand with fingers it is *palmately lobed* (wall-ivy). It is not necessary for the number of lobes to be exactly five.

In a compound leaf, the leaflets may be in a palmate arrangement (globe-flower), or arranged like the plumes of a feather (*pinnate*). The vetch is a good example. If there are only three leaflets, as in the clover and wood-sorrel, the leaf is *tri-foliate*.

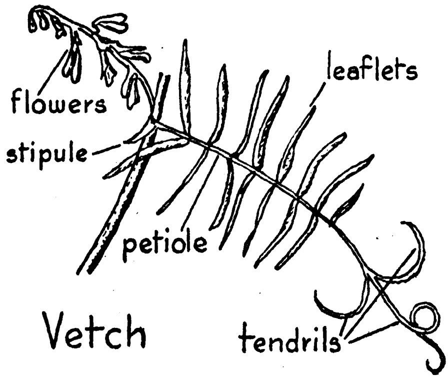


FIG. 12.—Leaf-tendrils.

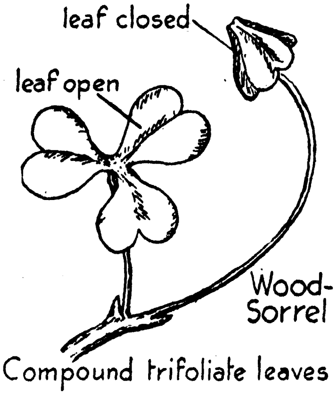


FIG. 13.

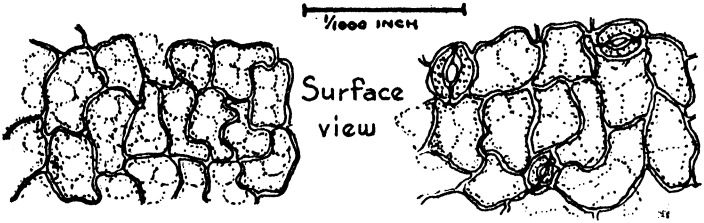
Many leaf-shapes are named from their resemblance to common objects: examples of this are the cordate (heart-shaped), ovate (egg-shaped), hastate (spear-shaped), and linear types of leaf. The names come from the Latin names of the objects they resemble.

There are many other features of leaves which enable botanists to recognize and describe particular plants. For our purposes, it is important to know the main types, simple and compound, and that there are many stages between entire and deeply segmented leaves.

INQUIRY 11. Find, from living plants, preserved leaves, or (only in the last resort) from illustrations, one example of each of the leaf-shapes mentioned above.

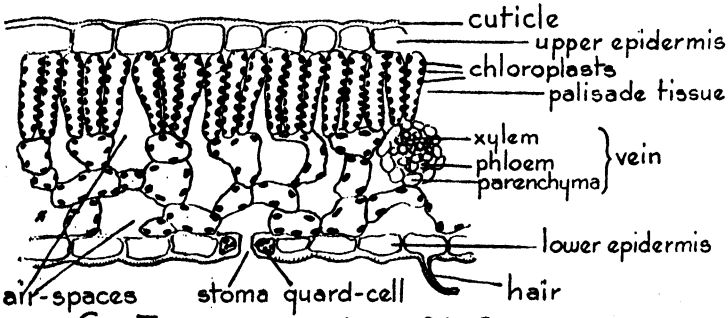
Internal Structure of Leaves.

The chief work of the leaf is concerned with respiration, nutrition, and *transpiration*. This last function is necessary in leafy plants because their method of carrying out the other two functions involves the use of large quantities of water. Transpiration is the plant's method of disposing of surplus water.



A. The palisade-cells show through the epidermis.

B. Underside, showing three stomata.



C. Transverse section of leaf.

FIG. 14.—Internal structure, dicotyledon leaf.

These functions are discussed in detail in Chapters VI and VII. All that need concern us now is that they involve a great deal of absorption and giving off of gases, and movement of solutions, and that the energy for all this work is obtained by the leaves from sunlight. With these facts as background, we pass on to examine how the leaf is constructed to carry out its functions.

It is important to become familiar with the microscopic appearance of the leaf, because in this way much information about the working of the plant can be obtained with little trouble.

Since the microscope operates by light which comes through the object (transmitted light), and not by reflected light, it is necessary to choose a thin leaf when examining the "solid" appearance of the leaf. It is also advisable to make it more transparent.

> INQUIRY 12. Place on a microscope slide a small piece of thin leaf, underside to the glass; cover with a drop of chloral hydrate solution and warm very gently, well above a spirit-lamp or bunsen flame. Cover with a cover-slip and examine with low and high-power. Draw the specimen.
>
> Repeat the inquiry with a second piece of leaf, but this time place the upper surface next to the glass. Compare what you see in both cases with Fig. 14, A and B.

These views are rather confusing at first because they show several layers of cells superimposed on each other. They become much easier to interpret when we have examined a transverse section of a leaf, in which we can see each layer of cells separately.

> INQUIRY 13. Take a small leaf, preferably from a fuchsia or purple saxifrage. Place it between two pieces of elder pith or carrot, to support it, and with a sharp razor which has been dipped in water, cut several thin sections at right-angles to the midrib.
>
> Sweep these off the razor into water in a watch-glass or small dish. Select one or two of the best and transfer them to a drop of water on a slide. Cover with a cover-slip and examine with low and high power. Make a sketch showing the general lay-out of the section, and a large-scale drawing of part of it.

Fig. 14 C shows the appearance of a leaf in transverse section. Both surfaces of the leaf have an *epidermis* whose outer walls form a thick *cuticle*, but the underside is pierced with many holes (stomata) through which gases can pass. The cuticle is waterproof and gasproof, being impregnated with cutein produced by the epidermal cells.

Below the upper epidermis is a layer of *palisade-tissue*, consisting of long sausage-shaped cells ranged side by side and containing large numbers of chloroplasts in the protoplasm lining their walls. Below the palisade-tissue is a layer of large irregularly-shaped cells, with many air-spaces among them and some chloroplasts inside them. This tissue is called the *spongy parenchyma* and forms, with the palisade-tissue, the *mesophyll* (Greek: middle-of-the-leaf). Then comes the lower epidermis, forming the leaf's underside.

At intervals in the lower epidermis are openings leading into the air-spaces of the spongy tissue, and guarded by cells containing many chloroplasts. The openings are called *stomata*, and the green cells on either side are *guard-cells*. These stand out because the other cells of the epidermis are colourless.

By comparing this view with the surface view, it is seen that the guard-cells are shaped roughly like the segments of an orange. They can change their shape slightly so as to open and close the space (stoma) between them (see Chapter VI, page 90.)

The *midrib*, whose cut surface will be seen in the mesophyll, has the familiar appearance of a vascular bundle, except that, as the leaf soon reaches its full size, there is no need for cambium, which is therefore absent.

Here is a brief note on the work done by each type of tissue. This subject is referred to again in Chapters VI and VII.

The epidermis, which is transparent, protects the leaf, being waterproof and air-tight, except for the stomata. Thus it is possible to spray plants with poisonous liquids to kill pests, without injuring the leaves.

The palisade-cells trap with their chlorophyll the energy of sunlight, and use it to convert carbon dioxide absorbed by the spongy parenchyma, and water from the veins, into molecules of sugar, and then starch.

The spongy tissue absorbs carbon dioxide from the air-spaces, in daylight. It also absorbs, day and night, the oxygen which the plant breathes, and returns unwanted gases and water-vapour to the air-spaces.

The guard-cells, by altering the size of the stomata, regulate the intake and output of gases according to the changing needs of the plant.

The veins bring up from the roots the water and salts needed for the manufacture of food, and distribute the food in solution to other parts of the plant, where it may be used at once or stored.

Modified Leaves.

In some plants the leaves have to carry out unusual functions, and this results in their having special structure. A simple example is the *Water-lily* (Fig. 15), whose leaves float on the surface of ponds, and keep the stem in a position which enables the plant to flower above water. These leaves are very large and covered on the upper surface with a layer of wax to prevent them from becoming waterlogged. There are no stomata on the underside, where they could not function, but the upper surface is well supplied with them.

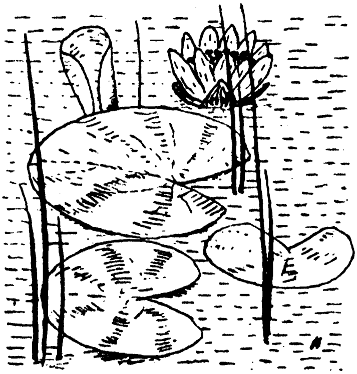


FIG. 15.—Water-lily.

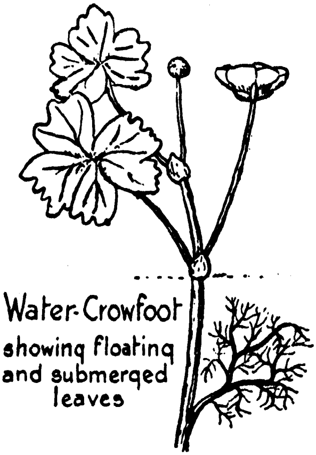


FIG. 16.—Modified leaves.

The *Water Crowfoot* has some of its leaves entirely submerged and, as stomata would be useless under water, the difficulty is overcome by having the submerged leaves very thin and divided. This gives them a big surface in proportion to their size, and they are thus able to pass the necessary gases in and out of their tissues, in solution (Fig. 16).

Plants which live in very dry places often protect their leaves from too much loss of water by having the stomata set at the base of a groove, as in the *Heather*, or by having the under surface of the leaf rolled inwards, as in the *Crowberry* (Fig. 17). Such plants are Xerophytes (Greek: plants of dry places).

Some plants *climb* by the help of thread-like leaves or leaflets called *tendrils*, which coil round the nearest support and hold up the weight of the shoot. The *Yellow Pea* (Fig. 18), has its leaves completely transformed into tendrils, while the functions of the leaves are carried out by leafy stipules (page 35). The *Vetch* has a compound leaf whose end-leaflets are modified into tendrils (Fig. 12).

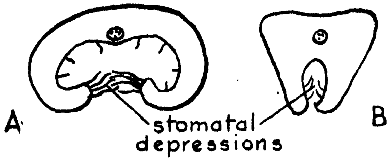


FIG. 17.—T.S. of xerophytic leaves.
(*a*) Crowberry. (*b*) Heather.

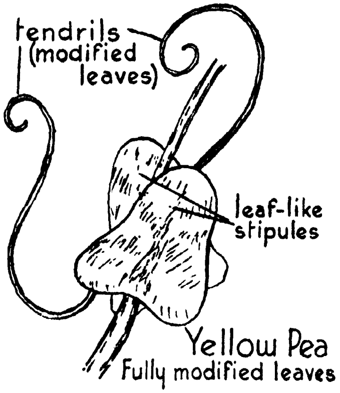


FIG. 18.

A few plants eke out their rations by feeding on insects. *Insectivorous* (Latin: insect-eating) plants are commoner in tropical countries, but two fairly common examples, the *Sundew* and the *Venus' Fly-trap* occur in this country on marshy ground.

The leaves of the sundew are small and disc-shaped, and the upper surface is covered with long outgrowths, like stout hairs,

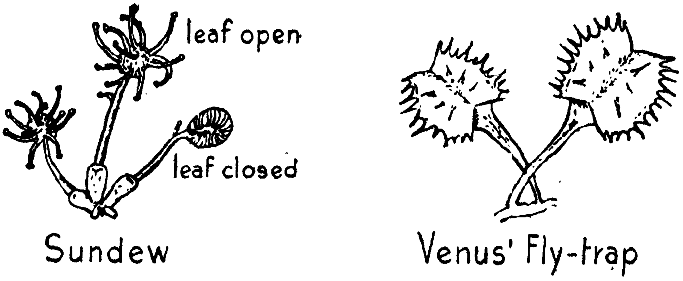


FIG. 19.—Insectivorous plants.

each with a sticky globule at the end. When an insect alights on the leaf, the long glands immediately bend over it and pour out more sticky fluid. The insect is trapped, the leaf closes slightly, and in a few days' time, when the leaf opens out again, the shrivelled skeleton of the insect is blown away by the wind, and the plant is the richer by a small but valuable diet of food, rich in nitrogen compounds, which are scarce in the soil where it grows.

In some plants, particularly in hot countries, the leaves may reach an enormous size. The *Victoria Regia* has floating leaves with a turned-up edge, and one leaf is easily able to support the weight of a small child. The *Banana* plant has leaves which reach a length of about ten feet.

Other leaf-modifications are described on page 105.

Stipules.

The word *stipule* was used in describing the yellow pea (page 34). In many plants there is an outgrowth at the base of each leaf. It may be just a brown scale, or a leaf-like structure, or a tendril. These structures are called stipules. They serve various purposes: generally their first task is to protect the axillary bud. When it opens they may wither, as in the case of the *Garden Geranium*, where they remain as papery scales; they may fall off completely, as in the *Wild Rose*; or they may remain green and help in the work of the leaves, as in the *Violet*.

Bracts.

Leaves which are closely associated with flower-groups are often different in size, shape, and sometimes even in colour, from the normal leaves of the plant. They are called bracts (Blue-bell, Fig. 20).

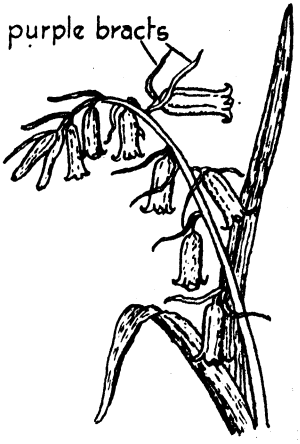


FIG. 20.—Bluebell, showing bracts.

The Inflorescence.

The final stage in the development of the shoot is the production of the flowering branches. In some cases each flowering branch produces only one (solitary) flower, but more often a number of flowers are arranged in a special order on the branch. Unfortunately the names of these arrangements are unfamiliar words, and not easy to remember. We shall therefore only refer to a few simpler types of inflorescence.

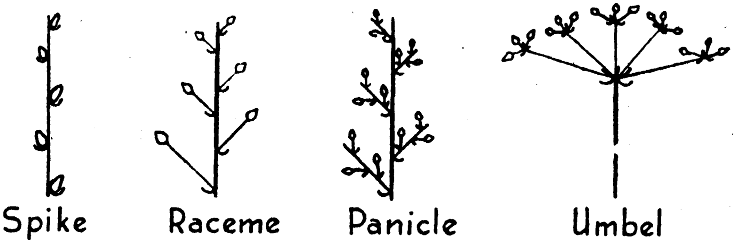


FIG. 21.—Inflorescences.

If the flowers arise directly without stalks on a simple stem, the inflorescence is called a *spike*. A good example is provided by the *Gladiolus*, whose spikes are popular as cut flowers for decoration.

A simple stem bearing rows of flowers with stalks is a *raceme*. This is a very common arrangement, seen in the *Bluebell*, *Foxglove*, etc.

If the stem bears branches, and the stalked flowers are all on the branches, the result is a *panicle*. The *Harebell*, sometimes called the Scottish bluebell, is an example.

When all the flower-stalks arise at the same level, but are of different lengths so that the flowers form a flat sheet, this is called an *umbel*. There is a large family of flowers where this arrangement is the rule, called the *Umbelliferæ*. The *Parsley* belongs to this family.

A large number of flowers crowded together into a compact *head* is the arrangement typical of another very large family of flowers, the *Compositæ* (*Daisy*, *Dandelion*, coltsfoot, wild chrysanthemum, etc.).

A flower in an inflorescence is often situated in the axil of a bract.

The parts of a flower, and their functions, are dealt with in Chapter XX.

Comparison of Shoot and Root.

You should now have in your mind a general picture of the main features of the shoot and root, and it will be useful to see how they resemble and how they differ.

They are both normally long slender structures, usually branched.

Each has a protective outer coat which is almost entirely waterproof.

The ground-tissue is similar in both, and a continuous vascular system of xylem and phloem runs through the entire plant.

The stem is usually green, whereas the root contains no chlorophyll.

The branches of the root arise under its surface, but stem-branches arise from buds which are formed from the surface-layer.

The tip of the root is protected by a root-cap; the tip of the shoot is protected by the overlapping leaves of the bud.

The stem grows away from the ground and towards the light, but the root grows into the ground and away from light. There are exceptions to this which will be described in Chapters VII (food storage) and XVIII (tropisms).

The mechanical structure and distribution of strength is different because the needs of the shoot and root differ in this respect.

The functions of the shoot and root are different (see Chapter VI).

A root may be distinguished from a shoot by the fact that the root never bears leaves or buds.

Further references to shoots and roots will be met frequently in later chapters. Use the Index when you want to collect these references.

QUESTIONS

SECTION A.

1. Write short definitions of parenchyma, xylem, phloem and cambium.
2. Describe and illustrate three types of modified stem.
3. Write a concise illustrated account of the appearance of the shoot of any (named) herbaceous plant which you have studied.
4. Compare the structure of the shoot and root in a dicotyledon.
5. Name two plants in each case with leaves which are (*a*) simple and entire, (*b*) simple toothed, (*c*) simple divided, (*d*) compound palmate.
6. Discuss the forces which (*a*) the root, and (*b*) the shoot, has to withstand, and state briefly how the plant is equipped to deal with them.
7. Give fully-labelled diagrams to show (without additional description) three types of leaf-modification.
8. How does the internal structure of a leaf help it to carry out its functions?

SECTION B.

1. Why are cress-seeds used in preference to others in Inquiry 4?
2. Think out and try an experiment to compare the pulling-strength of a shoot with that of a root. (Use a bean-seedling, obtained as described on page 160, Chapter XII.)
3. If a leaf is buried in the ground it quickly rots. Why does not this happen to the roots of plants?
4. Cut a brussels sprout transversely and make a labelled diagram of it to correspond with the L.S. shown in Fig. 5. (Make cuts at various levels and draw the one which shows most details of structure.)

CHAPTER III

TREES

In the previous chapter we learned that some herbaceous plants live for several years (perennials). They do so by producing an entirely new above-ground shoot each year. This chapter deals with perennials of a different kind, where the shoot, once established, goes on living for years. These are called *woody perennials*, and are all either *shrubs* or *trees*.

A tree is a woody perennial with a prominent main stem called a *trunk*, or bole, with branches arising from it, usually at a considerable height from the ground.

A shrub has no trunk; instead, a number of stems arise side by side, and branching begins just above soil-level.

It is sometimes hard to say whether a particular plant is a tree or a shrub, because its shape may be affected by abnormal situation, or by interference with its growth by pruning (page 48).

In Britain, all the native trees are dicotyledons.

Deciduous Trees and Evergreens.

The majority of British trees lose their leaves in autumn, and pass the winter in a kind of sleep called *suspended animation*. They are alive, but do not grow or feed during this period. Such plants are *deciduous* (Latin, *decidere*: to fall down or die).

Other trees, such as the holly and the Scots pine, keep their leaves through the winter; but even here the activity is greatly reduced during cold weather. They are called evergreens, for obvious reasons.

General Features of Trees.

Because of the size of its shoot, a tree requires a very substantial root system. It acquires this by dispensing at an early stage with its tap-root, and developing a very large number of branches from its lateral roots. These branches spread out horizontally just below the soil, and form a supporting platform for the whole tree. The tap-root is lost in the tangle.

In spite of this great root development, it is still only near the tips that root-hairs occur. The older parts of the roots are used for conducting, and not for absorbing. They also anchor and support the tree.

Secondary Thickening. As the number of rootlets increases, the original lateral roots are called on to carry more and more liquid. To enable them to do this, new layers of conducting tissue are developed by the cambium so that the stele increases in diameter every year.

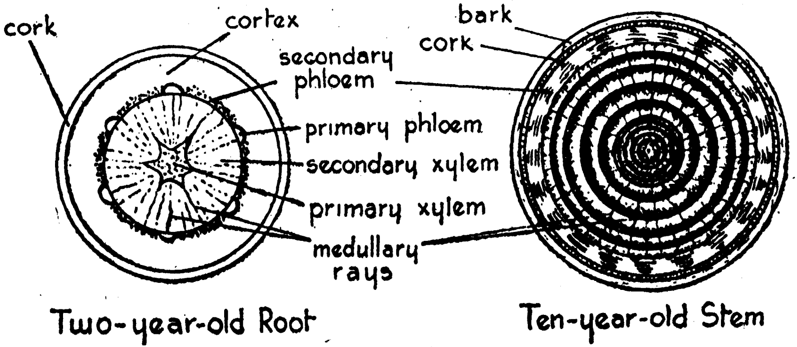


FIG. 22.—T.S. root and stem of Lime.

At intervals round the ring of cambium are a few cells which, instead of producing new vessels, always produce parenchyma cells. This results in the stele being traversed by radiating lines of parenchyma tissue, called *medullary rays* (Fig. 22).

All the xylem and phloem produced after the first year is called *secondary tissue.* As may be expected from the position of the cambium, this secondary tissue is all developed between the primary xylem and the primary phloem; so in an old root, the primary xylem is in the centre of the stele, while the primary phloem is around its circumference.

Annual Rings. Secondary thickening also takes place in the shoot. Here, since the primary tissue is in bundles, a new cambium arises, joining the cambium of the bundles into a ring, and the secondary tissue is therefore also developed in rings, being formed by this cambium (Fig. 22).

Secondary vessels grow in the spring, summer and autumn. During the spring, there is normally the year's heaviest rainfall, and the roots are absorbing a great deal of moisture to supply the needs of the developing leaves. This moisture has to be transported up the stem, and accordingly the vessels formed at this time are large. As a result, the *spring wood* is light in texture; when the vessels are empty the wood contains many air-spaces.

In the summer, after the leaves are fully grown, the tree's moisture requirements drop sharply, but the weight of the shoot has greatly increased. Consequently the *summer wood* is thick-walled and compact, with much narrower vessels. In autumn, when very little growth occurs, the vessels formed are narrower still.

Thus every year a new ring of wood is laid down showing, when seen in transverse section, a gradual change from light porous wood to dark compact wood. This is an *annual ring*, and by counting them it is possible to discover the age of a tree. In California there is a living tree, the General Sherman Big Tree, which is over three thousand years old.

> INQUIRY 14. Take the first opportunity to examine the stump of a felled tree, and observe the annual rings. Notice how they vary in thickness according to the weather of each year; and how each ring is thicker on that side of the tree which had the better water supply.

Dead Wood. As each annual ring is formed, the older rings become more and more compressed and finally die, often depositing gums or crystals within the cell-walls before doing so. This *secretion* occurs in the phloem, as the xylem is already dead, even when in use. In this way, *heart-wood* is formed which is often very hard and strong, in contrast to the *sap-wood.*

As the living tissues of the trunk are just below the surface, a tree can be fatally injured by removing a thin strip from the whole circumference. This sometimes happens to young trees (saplings) in severe weather. Snow prevents gnawing animals like the rabbit from finding grass, so they nibble all round the trunks of the saplings, cutting off the sap supply to the branches. Whole plantations have been ruined in this way.

Cork. As the circumference of a woody stem increases yearly, the epidermis soon finds it impossible to stretch far enough to cover it, and ruptures. To protect the underlying tissues, a special layer of *cork* is produced from a new cambium, the *cork-cambium*, which forms in the cortex. The protective nature of cork will be realized if you remember that it is used for stoppering bottles, for floor coverings and other forms of heat insulation, and for life-belts. Indeed, if it formed an absolutely continuous sheath for the stem it would quickly suffocate the plant.

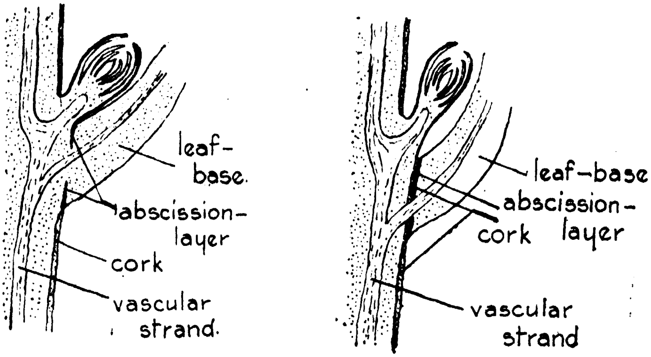


FIG. 23.—Stages in leaf-fall.

To prevent this from happening, the cork is dotted all over with little patches of loose tissue, called *lenticels* (Latin: meaning little lentil, because of their shape and size). These are easily seen on the stems of trees we shall presently consider.

Abscission-Layer. A special growth of cork occurs in early autumn, at the base of the leaf in deciduous trees. This serves the double purpose of cutting off the supply of sap to the leaf, which withers and drops off, and of sealing the wound thus formed, to *prevent bleeding* (loss of sap), which would be a serious matter in a tree with many thousands of leaves. This layer of cork is called the *abscission-layer* (Latin: "cut-off") (Fig. 23).

Bark. Cork is formed slightly below the outer tissues of the stem and, as explained above, it insulates these from the remaining living tissues of the plant. As a result, the outer layers of tissue starve to death, and begin to crack or peel. This dead tissue is called *bark*.

Typical British Trees.

Later in this chapter the following trees will be described and compared in detail: oak, beech, horse-chestnut, and Scots pine. Just now we are more concerned with the broad differences between some of the commonest trees found in these islands.

The first distinction to notice is that between the *narrow-leaved Conifers* and the *broad-leaved Flowering Trees.* The conifers (Latin: cone-bearing) also bear flowers, but their stamens and ovules are to be found in cones. They have tall straight trunks (used for making telegraph poles), and are all evergreen, except the *Larch.* Well-known examples are the pine, fir (Christmas-tree), spruce and cedar. Their leaves are narrow in comparison with the length (needles), and generally dark-green or grey-green; the larch provides a striking exception with its bright green foliage, which, however, darkens in the summer.

The internal structure of the wood and leaves is different from that already described for a woody plant, but does not concern us in this course.

Of the flowering trees, only three common examples have their leaves arranged in pairs on opposite sides of the stem. These are the ash, the horse-chestnut, and the maple family, including the sycamore.

In all the other trees, the leaves are arranged alternately, each leaf being on the same side of the stem as the next-but-one above or below it (Fig. 24). Many shrubs, however, have opposite leaves.

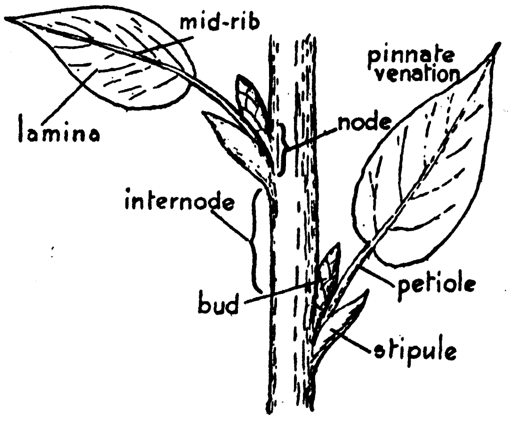


FIG. 24.—Typical features of a woody twig.

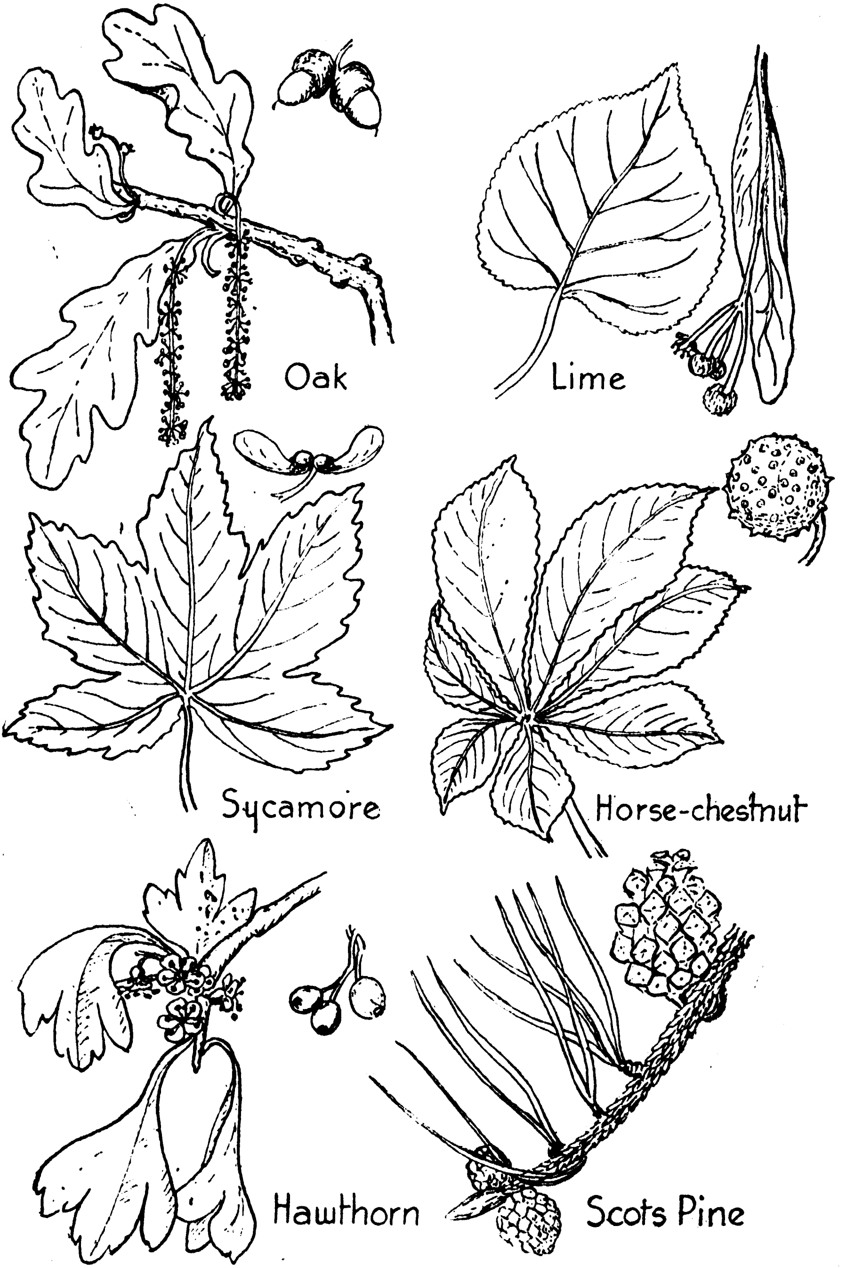


FIG. 25.—Leaves, flowers and fruits,

An obvious choice for a typical British tree is the *Oak*, although it grows in all the temperate lands of the Northern Hemisphere. It figures greatly in our history and tradition, from the time of the Druids who considered it sacred, through the centuries when it was the backbone of our navy and merchant fleet, to modern times, when furniture of English oak is still among the finest in the world. The tree lives for many years—some living oak trees are nearly a thousand years old.

The *Ash* is easily recognized by its long slender grey-green twigs with black buds, and its compound leaves, each with about five pairs of opposite leaflets and a terminal one. It has a winged fruit (page 266).

The *Sycamore*, though very common, is not a native British tree. It has broad lobed leaves, and its fruit is winged (page 44).

The *Lime*, which is commonly planted along roads in towns, has simple toothed light-green leaves. The lower part of the trunk often has large bunches of shoots growing from cushion-like patches. The flowers produce large quantities of fragrant nectar which often drips to the ground. The fruit hangs in clusters of up to four little balls from a stalk which is attached to a bract (Fig. 25).

The *Alder* is a tree which usually has a tidy, conical outline; its flowers are in catkins which, being woody, resemble pine-cones. The leaves are broader at the tip than at the base, as though the stalk has been attached at the "wrong end". The buds are on stalks, and covered with a purple down of protective hairs.

The *Silver Birch* deserves mention as one of our most graceful trees, with its almost white bark, slender twigs, and simple sharply-toothed leaves.

The *Beech* has an unusually smooth grey bark. Its vivid green leaves are

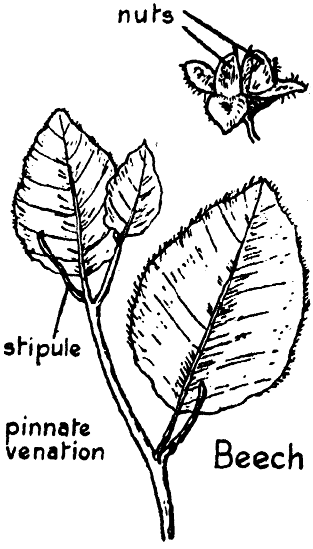


FIG. 26.

very thin and papery and stir in the lightest breeze. The ornamental copper beech is not a separate species and often grows from the seeds of ordinary beeches.

The Tree's Year.

We must now go into greater detail, and our method of doing so will be to consider the needs and activities of the tree during each of the four seasons, and describe how each of our four representative trees copes with the situation.

Trees in Winter.

As winter is the time when trees are least active, it will be convenient to begin with this season.

Trees like the horse-chestnut, beech and oak, whose leaves are delicate, shed them in preparation for winter, so that when the cold weather comes the tree is well equipped to face it.

The stem and branches are covered with cork, which resists cold conditions, and the lenticels allow just enough air to pass to keep the tree alive. There is no growth or feeding at this time, so there is little demand for carbon dioxide. For the same reason, the movement of liquid in the plant is negligible.

Winter Buds. When we considered buds in Chapter II, we learned that in their early stages they were often protected by stipules. This is sufficient protection for buds which develop in summer, but in woody perennials, the whole of a year's growth of new branches, leaves and flowers is laid down in miniature the previous year in buds which have to survive the winter. These *winter buds* are therefore vital organs of the plant and require special protection.

Winter Twigs. The features briefly referred to above are best suited by examining twigs in winter. The simplest, because of its size and the clearness of its marking, is the horse-chestnut twig: so we shall deal with that first, and then compare the others with it.

Horse-Chestnut Twig.

> INQUIRY 15. Examine several twigs of this tree, obtained during the winter (Fig. 27). Notice the fairly smooth brown bark, covered with raised dots, a little lighter in colour. These are

the *lenticels*. Most of the twigs will be found to end in a single large *terminal bud*, encased in dark-brown *bud-scales*, and having a sticky fluid at the tip. This fluid is *resin*, and serves to keep out frost, rain, and insects which might injure the delicate structures inside.

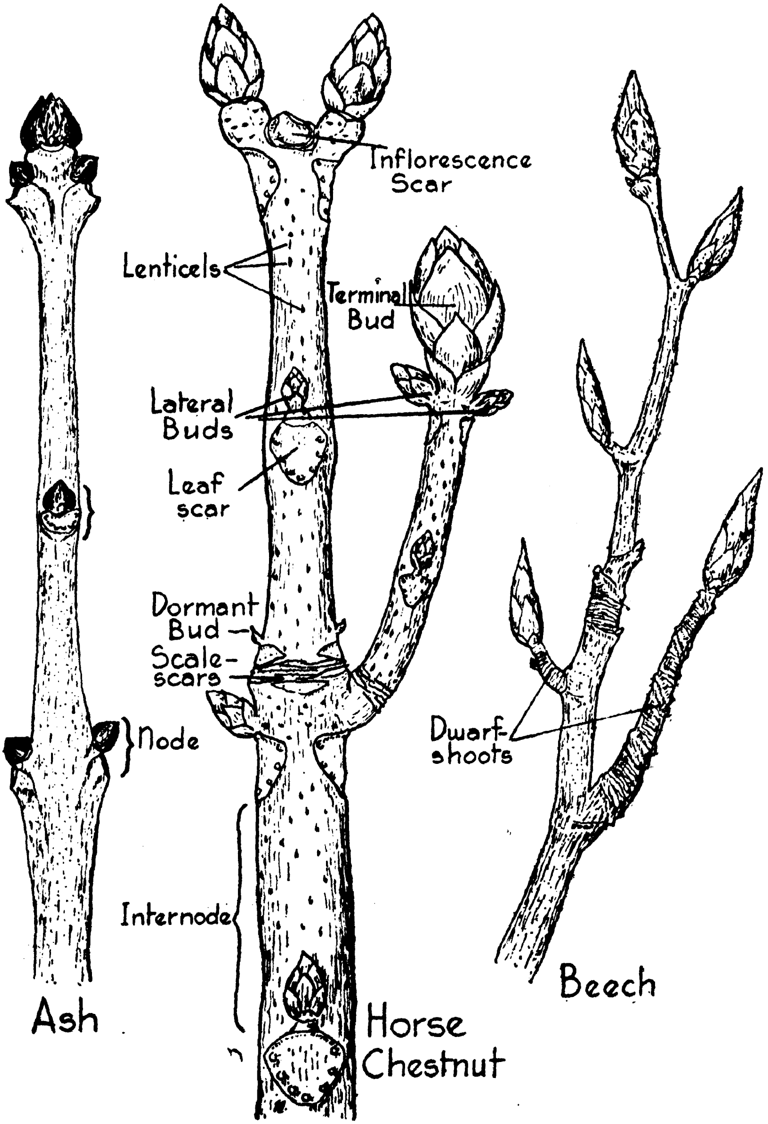


FIG. 27.—Twigs in winter.

The twig will also bear several *lateral buds*, arranged in pairs on opposite sides of the stem. Each pair is at right-angles to the pair above and below it. Beneath each lateral bud is a very prominent shield-shaped *leaf-scar*, showing the place where the leaf was attached before it withered and fell off. The scar is covered with cork, and has on it a horse-shoe pattern of raised dots which are the points where the *vascular strands* passed from the stem to the leaf. There are usually seven of these, one for each leaflet, but the number varies slightly. The position of the leaf-scar shows that the lateral bud developed in the *axil* of a leaf (page 20), and it is often called an *axillary bud.*

Some, at least, of the twigs you examine will have some very small axillary buds which show no signs of life. These are *dormant buds,* and will not develop unless the other buds, or the whole stem above the dormant bud, suffer injury.

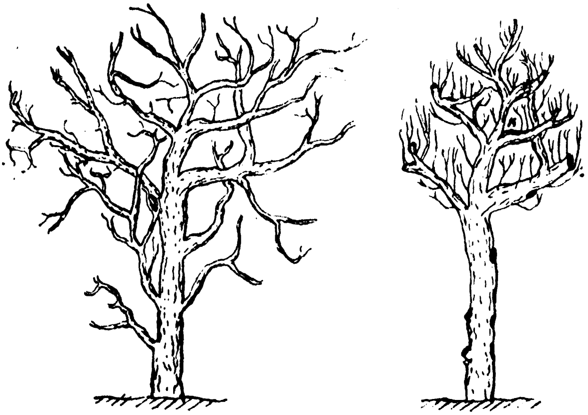


FIG. 28.—Tree, before and after pruning.

Advantage is taken of this fact when it is desired to control the shape of a tree or shrub. The process is called *pruning*, and consists in cutting off the tops of the shoots. The dormant buds then develop, and the growth of the shoot then becomes stocky and thick-set. A good example is provided by fruit bushes, such as black currants, and ornamental hedge-plants, such as privets. Roadside trees are pruned to prevent their interfering with traffic, or cutting off the light from buildings.

Some of the twigs will possess rings of scars encircling the stem. These are *scale-scars*, left behind when the bud-scales fell off a previous year's terminal bud. It follows then, that all the stem from its tip to the first set of scale-scars represents *one year's growth*: and the length of stem between two successive sets also represents one year's growth. It is thus possible to find the age of a twig by counting the number of scale-scar groups. A group of scale-scars is often called a *girdle-scar*, because it encircles the stem.

If you are lucky, you may see a twig which ends, not in a terminal bud, but in a curious saddle-shaped scar, with two lateral buds projecting beyond it, as in the diagram. This is a *saddle-scar*, and marks the place where an inflorescence was situated. It is therefore often called an *inflorescence-scar.*

You will remember that in Chapter II it was stated that a bud may give rise to either a leafy branch or a flowering branch. In the horse-chestnut the inflorescence always arises from a terminal bud: and therefore the saddle-scar which is formed when it dies off is always at the tip of a twig.

Structure of Winter Bud. As already stated, the bud is designed to protect the following year's growth inside it. In the horse-chestnut, as in most winter buds, this protection comes mainly from special overlapping scales, which are modified leaves, as can be seen by carefully removing them one by one. As the inner scales are reached they are seen to be green and leaf-like.

Beneath the scales the true leaves are found, swathed in a mass of cottony hairs which afford further protection. The leaves are set on a very much compressed stem, the length of the internodes (see Fig. 24) being almost zero. Axillary buds are already present in the axils of the leaves.

INQUIRY 16. Place a few twigs of horse-chestnut in water; leave them in a warm place for a few weeks, and observe the stages in the opening of the buds. It is a good plan to cut one of the buds lengthwise, removing half of it and leaving the other half to open on the twig. It will open before the other buds.

INQUIRY 17. Take to pieces the half-bud you have removed and verify the facts given above.

INQUIRY 18. Make a careful drawing of a horse-chestnut twig, labelling as many of the above features as possible.

Beech Twig. The most striking difference between the beech twig and that of the horse-chestnut is in the arrangement of the buds. In the latter, the buds occur in opposite pairs. In the beech there is only one bud at each node, as explained on page 43. The main result of this is that the growth of the twig is zigzag instead of being comparatively straight: and there is no need of a terminal bud.

A feature which is peculiar to the beech is the long slender shape of the buds. Most of them are slightly flatter on the side next to the stem. It will also be noticed that branches of the twigs often bear a large number of girdle-scars in a few inches, denoting very slow growth. Such restricted branches are called dwarf-shoots. These two features, together with the fine reddish-brown tint of the buds, make the twig easy to recognize.

The bud-scales in the beech consists mainly, not of modified leaves, but of stipules.

> INQUIRY 19. Examine and draw a twig of the beech and compare with the horse-chestnut. Dissect one of the buds and draw its parts.

The oak-twig is so rough and gnarled that its features are difficult to distinguish, and it will be sufficient to notice the clustered arrangement of the buds and the numerous girdle-scars showing the slow growth of the twig. The buds are yellowish-brown.

General Appearance of Trees in Winter.

The horse-chestnut has scaly bark, and its branches are "up-swept" at the ends so that the terminal buds, which are easily seen from a distance, stand almost vertical.

The beech is recognized by its smooth bark and the sharp outlines of its slender twigs, forming a lacy network against the sky.

The oak has very rugged bark with deep lengthwise furrows. The tree is usually rather squat, with a gnarled, wide trunk and thick branches.

Spring—the Reawakening.

When the weather becomes warmer, the root-hairs again become able to absorb moisture from the soil, and the warmth of the sun stimulates the buds to open. As the bases of the bud-scales become turgid (swollen with water) they bend outwards and allow the sunlight to reach the new shoots. These rapidly absorb water from the roots and begin a period of very quick growth, occurring chiefly in the internodes. This causes a great increase in the length of the new stem, and the organs on it become spaced out and are enabled to carry out their functions. The bud-scales fall off, leaving the scale-scars to mark the beginning of the year's growth.

Summer—Flowers and Fruit.

By the beginning of summer all three trees are in full flower. The horse-chestnut flowers appear in magnificent upright inflorescences like large candles (seen from a distance), at the tips of the outer branches. In the oak, the female flowers are enclosed in bracts, and the male flowers hang in catkins, about two inches long. The beech has its flowers grouped at the ends of stalks (peduncles) about two inches long.

The flowers of the oak and beech are not handsome, since, being wind-pollinated (page 258), they have no need to attract insects.

The fruit of the horse-chestnut is a smooth brown nut (conker), found inside a thick green spherical case which is covered with short green spines (Fig. 25). There should be three nuts in each, but often only one develops. A kind of soap can be extracted from them.

Beech-nuts are enclosed, usually in pairs, in a scaly cup formed from the bract which was at the base of the inflorescence. They are edible (good to eat).

The oak fruit is the well-known acorn, and is only half-enclosed in the remains of the scales which surrounded the female inflorescence. The fruit is sometimes used as pig food, or for making coffee substitute.

Autumn—the Decline.

This season is largely occupied by the closing-down processes by which the plants prepare for winter. The fruit-stalks wither, allowing the fruit to fall to the ground, where it may be picked up by animals or transported by other means to a situation where the fruit-case can dry and split open, releasing the fruits. The fruit may then be eaten, when the seeds will survive the animals' digestive processes, or the outer covering of the fruit may just rot away, exposing the seed in time for germination.

The leaves begin to wither, owing to the growth of the *abscission-layer* (Fig. 23); and when this is complete they fall off. Meanwhile the buds for the following year's growth are developing in the axils of the leaves.

The Scots Pine.

We have left the Scots pine out of the above descriptions because, though it is a fine tree, reaching to a height of a hundred feet, it shows many important differences from the other trees.

In the first place, the *ovules* (Latin: little eggs) of the female inflorescence are not enclosed in ovaries, but simply rest on scales which are thick and soft, and at first are closely pressed together to protect the ovules.

Secondly, a resting-period of a whole year passes between the transfer of pollen from the male flower to the female, and the fertilization, or fusion of the pollen-grain with the ovule. Then another year elapses before the seeds are ripe: so from formation of the flowers to dispersal of the seeds three years go by.

Thirdly, the internal structure of the wood of the pine is quite different from that of the trees we have studied so far.

Lastly, the leaves of the pine are specially designed to conserve water and sap, so the tree is able to grow high up on bleak hillsides where the soil is shallow and there is little warmth; and the leaves survive three complete years before dying away.

With these points in mind, we can now make a rapid survey of the life-cycle of the Scots pine, which is typical of the great family of conifers.

The wood is rather soft, and the bark is a rich red-brown colour, with a rough surface. The trunk is straight and tapering, and the lower part free from branches: though this last feature is not so well seen in the pine as in some other conifers. The leaves are in pairs, and consist of needles which are flattened on one side; the flat surface of each leaf faces the flat surface of its fellow. The twigs are covered with the scaly bases of old leaves (Fig. 25).

Near the tips of young shoots are small *cones* consisting of thin scales bearing many stamens. These produce so much pollen that in a gentle breeze near a pine-wood one may often see a pale-yellow cloud of the pollen grains.

Each grain has a pair of little air-bladders which hold it up in the air, much as water-wings hold a boy or girl up in the water when learning to swim.

The female cones are found farther back on the twigs. In their first year they are less than half an inch long and pink in colour. At the beginning of summer their scales come apart slightly to allow the pollen to be blown into the ovules, two of which rest on the upper surface of each scale. Then they close up for a year.

The following summer the pollen fuses with the ovule and the cone begins to grow until, by the end of the third year, it has reached a size of two inches, its scales have become woody and brown, and the fertilized ovules have turned into winged seeds. The scales now open out again, and the seeds drop off and glide away on the breeze (Fig. 29).

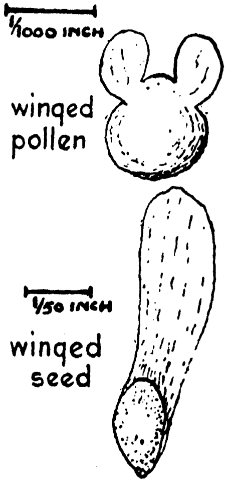


FIG. 29.—Pollen and seed of Scots pine.

INQUIRY 20. Examine twigs of Scots pine and try to find cones of the first, second and third year. Notice the situation and shape of the leaves, and draw a pair of them.

Uses of Trees.

In conclusion, it will be useful to point out some of the ways in which trees are of service to Man.

While growing, trees are of use in consolidating the soil, in sheltering meadows from cold winds, and in helping to balance the moisture-content of the neighbourhood. They absorb water after heavy rain, preventing the soil from becoming waterlogged: and in hot weather they return moisture to the atmosphere, preventing it from being too dry.

Many trees provide edible fruit and so contribute to the world's food.

When cut down, trees provide timber whose uses are innumerable; here are a few examples:

Pine: woodpulp for paper, timber for furniture, matches, ships' masts, telegraph poles.

Cedar: cigar-boxes, pencils.

Oak: furniture, beams, boats.

Horse-Chestnut: the wood is of little value, but starch and soapy materials are extracted from the nuts. They are also sometimes used as a medicine for animals (hence the name).

Beech: the nuts are used for human food, and the wood for making shoe-lasts.

Elm: lock-gates, river-piles, and other uses under water.

Birch: the bark is used for kindling, and for making canoes: and the wood is used for making charcoal, and for beating naughty boys.

Maple: furniture, dance floors.

Ash: hoops, ladders, billiards cues, hockey sticks, scouts' staves.

Lime: pill-boxes, statues.

Box: engraving-blocks for printing, school rulers.

QUESTIONS

SECTION A.

1. Describe, giving diagrams of their leaves and fruits, four trees which you have yourself observed.
2. Compare a named tree with a named perennial herb, under the headings of (*a*) external appearance, and (*b*) internal structure.
3. Write concise definitions of (*a*) cork, (*b*) cambium, (*c*) medullary ray, and describe the functions of cork.

4. Explain the origin and significance of the alternate light and dark zones seen on the cut surface of a felled tree.
5. Make a fully-labelled diagram from memory of the winter twig of a horse-chestnut.
6. Describe the process of leaf-fall, and explain how it is of benefit to the tree.
7. Compare the winter bud of a tree with the summer bud of the brussels sprout, and explain their differences in structure.
8. Describe the changes which take place in the course of a year in the appearance of a named tree.

SECTION B.

1. Compare the deciduous and evergreen habit of life in trees, stating the advantages and disadvantages of each.
2. State, giving reasons, which you consider to be more highly organized: conifers or broad-leaved trees.
3. Make a list of the chief properties of wood, showing how they are of advantage to (*a*) the tree, and (*b*) to Man, using it as timber.
4. Describe the features you would expect to distinguish a tree which was at home on a mountain (above the snow-line) from one which normally grew on the rich soil of a moist sunny plain.

CHAPTER IV

ENERGY AND LIFE

All organisms carry out many forms of activity: that is, they do *work*. Work cannot be done without using up *energy*. Energy is, in fact, a capacity for doing work. It exists in different forms, which are recognized by their effects as heat, light, sound, motion, chemical action, electricity and magnetism. The energy of organisms appears mainly as heat, motion and chemical action.

Organisms cannot conjure energy out of nothing, and as they are continually expending it, we should expect that they must have some means of obtaining new supplies. They do this partly by the direct absorbing of heat from their surroundings, but mainly by the process of feeding or nutrition. The various forms of energy can be converted into each other, so it is not necessary for the energy taken in to be in the form in which it is later to be used by the organism.

Measurement of Energy.

Heat is the easiest form of energy to measure: so it is convenient to measure the energy in food by finding out how much energy it gives off as heat when it burns; though we are well aware that, inside the body, it will release its energy in other forms as well.

The scientific unit of heat is the *calorie*, which is the amount of heat required to raise the temperature of one gramme (about ten drops) of water by 1 °C. (one degree Centigrade). This is a very small amount of heat, so for convenience we use a kilogram-calorie, which is equal to 1,000 small ones. This is the calorie which is so often quoted in discussing the world food problem. Thus, we are told that an average man needs 3,000 calories a day. This tells us nothing about the nature of the food he needs except that it must supply him with so much energy. Three thousand calories of heat energy represents enough mechanical energy to raise a load of forty tons through a height of one hundred feet, or to lift a full-size railway train to a height of ten feet from the ground.

Sources of Energy.

The original source of all the energy on the earth is the sun. It radiates this energy to us through space (chiefly as heat and light), and on arrival the radiant energy is converted into other forms. Organisms absorb some of this energy, and either put it to immediate use in some other form, or convert it into a form of chemical energy in which it can be stored for future needs. This building-up of a reserve stock of energy-containing chemicals takes place in all organisms, except certain internal parasites (page 193) which pass their lives completely immersed in a solution of food-material.

It is to be expected then, that when an organism dies it will have considerable energy stored away in some form in its body. This fact is made use of by animals which eat dead organisms. Most animals do this (some eat them alive): those which feed on the flesh of other animals are *carnivorous* (Latin: flesh-eating); those which feed mainly on plants are *herbivorous* (Latin: grass-eating); while those which, like ourselves, prefer a mixed diet containing both plant and animal material are *omnivorous* (Latin: eating all sorts).

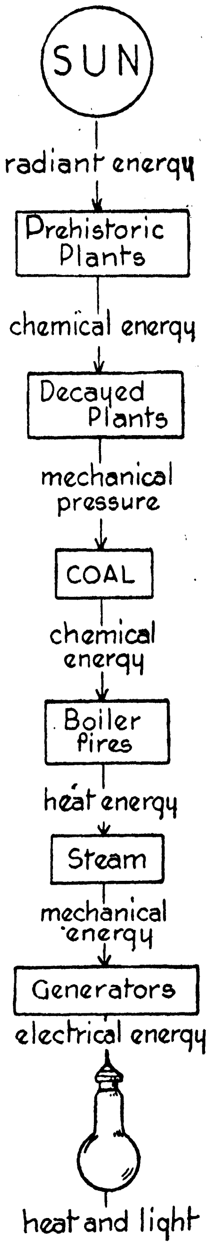


FIG. 30.—Energy chain.

Man makes use of the energy locked up in plant remains in other ways, apart from using them as food. Wood, coal, and oil, which are used as fuel, consist of organic remains. The coal contains a greater concentration of energy than the wood because it has been subjected to great mechanical pressure in the earth. Fig. 30 gives an example of the chain of energy-changes by which the energy of an electric light has been derived from the sun. You should work out other examples on the same lines.

Energy Changes in Chemical Actions.

Whenever a chemical action takes place, energy is either absorbed or released. Green plants are able to absorb directly the radiant energy of sunlight and incorporate it, along with

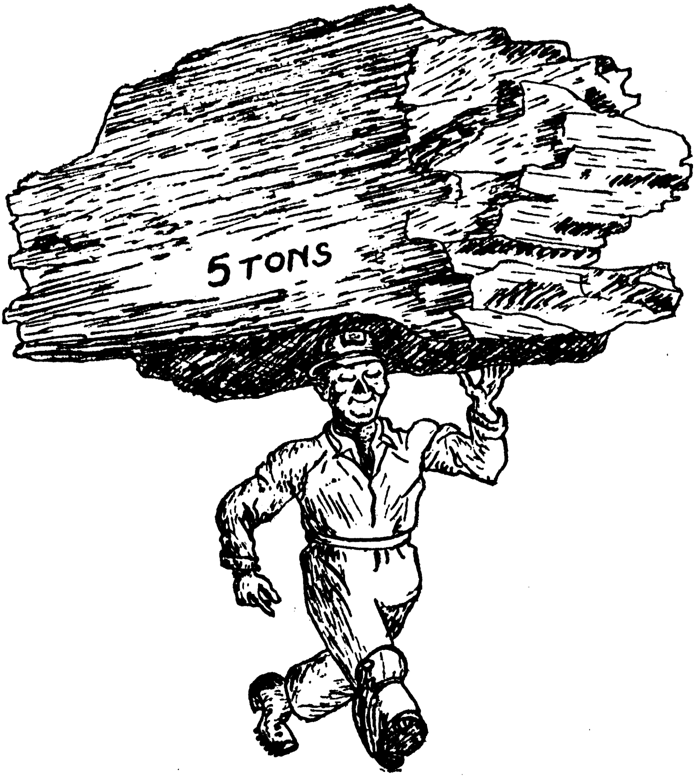


FIG. 31.—If all the energy in a slice of bread could be changed to mechanical energy, it would be enough to raise 5 tons through a height of 8 feet.

carbon dioxide and water, into more complex compounds such as sugar. The process is summarized thus:

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

$$\begin{matrix}\text{Energy of}\\ \text{sunlight}\end{matrix} + \begin{matrix}\text{carbon}\\ \text{dioxide}\end{matrix} + \text{water} \longrightarrow \text{sugar} + \text{oxygen}$$

The process is called *Carbon Assimilation* or *Photosynthesis* (Greek: building-up by light). Its external signs, which can be detected by the methods described on page 99, are the *absorption of carbon dioxide* and the *giving-out of oxygen*. The carbon remains (is assimilated) in the plant, in the form of solid or liquid compounds.

Releasing the Energy from Molecules.

It has just been seen that when sugar is formed oxygen is released. Under certain conditions oxygen can be restored and the sugar broken down again into carbon dioxide and water. The energy which had to be incorporated to hold the sugar-molecule together is then released, and becomes available for the organism to use according to its needs.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O + \text{Energy}$$

In a similar way, with the help of oxygen, other complex food substances may be broken down and energy made available.

The *absorption of oxygen for this purpose*, and the *giving-out of carbon dioxide*, are the external signs of *Respiration* (contrast this with carbon assimilation above).

Respiration and Burning.

The releasing of energy in respiration is, chemically, like what happens when fuel is burned. When paper, wood, coal, or indeed any kind of fuel burns, the reaction consists in the combining of fuel molecules containing much energy, with oxygen, forming carbon dioxide and water, and releasing most of the energy in the forms of heat and light. The energy thus released may then be used for heating, illumination or power.

Thus it is seen that burning and respiration are two types of *oxidation*. The main difference between them is the rate at which they take place. Respiration is gentle oxidation, while burning is vigorous. Another type of oxidation, less vigorous than respiration, takes place when metal rusts; while a very vigorous oxidation is called an *explosion.*

INQUIRY 21. Respiration and burning may be compared, as regards their chemical effects, as follows:

By applying suction at the mouthpiece M of the apparatus shown in Fig. 32 a stream of air bubbles can be drawn through a solution of limewater for, say, ten seconds. By blowing down the mouthpiece, a stream of air from the lungs can be passed through a second solution of limewater. The first solution remains clear, but the second one turns milky. The milky appearance shows that the air from the lungs contains a considerable amount of carbon dioxide, whereas fresh air does not contain enough of it to produce any noticeable effect in ten seconds. Respiration produced carbon dioxide.

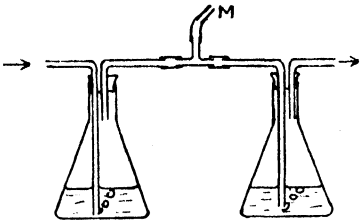


FIG. 32.—Exhaled air contains more carbon dioxide than fresh air.

Attach a piece of candle, about an inch long, to the rough side of a gas-jar cover with melted candle-wax. Light the candle and invert over it a clean dry gas-jar. The candle-flame soon dies out, showing that the jar no longer contains ordinary air. Pour some limewater into the jar. The limewater immediately turns milky, showing the presence of carbon dioxide. The burning of carbon compounds also produces carbon dioxide.

The Carbon Cycle.

The external effects of respiration and carbon assimilation counteract each other. It happens that, although carbon assimilation occurs only in green plants and, even there, only in daylight, the gas-exchange involved is so great that it makes up for the respiration, not only of the green plants themselves, but also of all other organisms. As a result, the *proportions of oxygen and carbon dioxide in the atmosphere as a whole remains constant.* There are, of course, other processes taking place which have slight effects on this balance—in winter, for example, the sea dissolves more carbon dioxide than it does in summer. This is fortunate, because in winter there are fewer green plants able to absorb the gas. Rain also dissolves carbon dioxide. Large quantities of carbon dioxide are released by fires and chemical processes.

The circulation of carbon between the carbon dioxide of the atmosphere, and various carbon compounds in the soil and in organisms, is called the carbon cycle, and can be shown by a diagram.

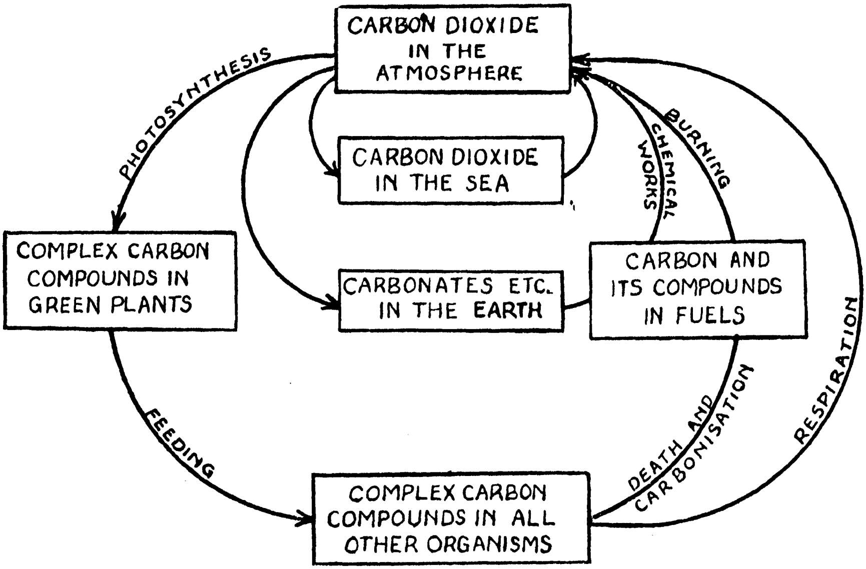

CARBON DIOXIDE IN THE ATMOSPHERE
PHOTOSYNTHESIS
CARBON DIOXIDE IN THE SEA
BURNING
CHEMICAL WORKS
COMPLEX CARBON COMPOUNDS IN GREEN PLANTS
CARBONATES ETC. IN THE EARTH
CARBON AND ITS COMPOUNDS IN FUELS
RESPIRATION
FEEDING
DEATH AND CARBONISATION
COMPLEX CARBON COMPOUNDS IN ALL OTHER ORGANISMS

FIG. 33.—Carbon cycle.

Storage of Energy.

The process of taking-in food is itself a form of work: and therefore an organism must have, in its body, a store of energy to enable it to acquire more energy by feeding. Energy is also stored for other reasons. Energy is being used up at every moment of an organism's life; but it would be inconvenient if the organism had to be taking in food at every moment to provide this energy. Instead, most organisms build up inside their bodies a store of food reserves which can be broken down at short notice when required.

The sugar molecule is one form of food reserve, but it is a very temporary measure because the molecule is easily broken down. A more permanent method is to convert the sugar into *starch*, which is insoluble in water and so is withdrawn from the scene of chemical action.

A leaf will soon become clogged with starch, so during the night when feeding has stopped, the plant changes the starch back into sugar solution, which is carried away to a part of the plant where it will not interfere with the work of the leaves, and is there changed back into starch. The leaves are thus freed for another day's accumulation of starch.

In animals a similar process takes place, but the storage-molecule in this case is called *glycogen*, or "animal starch".

Both plants and animals also store energy in oils and fats.

Emergency Supplies of Energy.

Sometimes a large amount of energy must be expended in a short time. This is commoner in animals than in plants. In such cases there is not time for the breaking down of food reserves by combining them with free oxygen, so they break down without its help. Glycogen, for instance, changes to *lactic acid*, releasing some energy in the process. When free oxygen does arrive it changes some of the lactic acid back into glycogen, and breaks the rest of it down in the normal way to carbon dioxide and water, releasing more energy.

If there is not enough food reserve at hand for all the energy required, the organism will obtain its energy by breaking down its own tissues. This is *starvation*, and the organism loses flesh as a result.

These methods are employed only in an emergency by most animals, because the partial breaking-down of food often produces poisonous intermediate substances, which would kill the organism if allowed to accumulate in large quantities.

> INQUIRY 22. Jump on and off a chair about twelve times in a minute. You will find that you feel warm, your heart is beating fast, and your muscles feel weak.

This is because of the process described above. The muscles weaken because their stored energy has been used up. Some of it has been converted into heat. The blood races round the body to replace the glycogen used up in the muscles and to bring the oxygen needed for recovery.

INQUIRY 23. Notice how the *fatigue* passes off in a few moments when the muscle has recovered its energy.

Aerobic and Anaerobic Respiration.

It has been seen that all organisms, except green plants, absorb most of the energy they need, locked up in the molecules of their food.

Nearly all organisms, including green plants, normally make this energy available when they need to use it, by employing oxygen to break down the food-molecules, or the chemical reserve-molecules which they have formed from their food. This breaking-down process is called *aerobic respiration* (Greek: living-by-air).

Most organisms can, in emergencies, break down their food without the help of free oxygen; plants, living at a slower rate than animals, can survive longer in this way. A few types of organisms seem to be quite independent of free oxygen for their respiration. Respiration without free oxygen is called *anaerobic respiration*, and is discussed more fully on page 94.

Energy and Life.

It will be seen that the life-processes of an organism are very closely bound up with the transfer of energy. Do not make the mistake of thinking that energy is the whole secret of life. It is only the "how" of living. The "why" is much more mysterious, and cannot be explained in terms of physics and chemistry. A non-living thing cannot be made alive by increasing its supply of energy. Every organism develops from a living parent or parents, from which it receives its life, along with a supply of energy to enable it to begin to carry out its own respiration and feeding.

In conclusion, it should be noted that food has other uses, besides providing energy. Some of these will be considered in the next chapter.

QUESTIONS

SECTION A.

1. Name the different forms of energy which appear during the process of boiling some water over a wood fire, and explain the presence of the energy in the wood in the first place.
2. What is energy? State where it comes from originally, and what forms it may assume (*a*) on its way to earth, and (*b*) after arrival.
3. Explain why, in spite of the continuous conversion of the oxygen of the atmosphere into carbon dioxide, the amounts of these two gases remain constant.
4. Why is coal called "bottled sunshine"?
5. Compare the respiration of a man with the use of petrol in a car.
6. Describe how a green plant obtains and stores its energy, and how it releases the energy when required.
7. Compare respiration and photosynthesis, under the headings: (*a*) chemical processes in organism, (*b*) effects in organism, (*c*) effects on atmosphere.
8. What is the use of starch to a plant?

SECTION B.

1. Describe what you think is the purpose of sleep in a human being.
2. Compare the oxidation of food with the chemical process of burning, under the headings of (*a*) chemical reaction, (*b*) physical effects.
3. Why is it more tiring to run up and down stairs ten times in ten minutes than to do it ten times in an hour?
4. Explain how green plants are essential to the life of all other organisms.

CHAPTER V

FOOD AND FEEDING

In Chapter IV it was seen that one of the chief uses of food is to provide organisms with energy. Many substances whose molecules contain plenty of energy are unsuitable as foods, either because the organisms are unable to break down the molecules, or because the resulting simple molecules would be harmful to the organisms. As it is, many foods yield slightly poisonous substances when broken down, so the organisms must be provided with an efficient means of ridding themselves of these harmful break-down products. Many of the minor ills of humans are caused by *constipation*, which is lack of regularity in the expelling of solid waste matter from the body, resulting in an accumulation of poisons in the blood.

It has also been pointed out that food has other uses, besides providing energy. A growing organism builds up its tissues from its food, which must therefore contain all the elements required for the tissues. A fully-grown organism has to replace worn tissues, and so needs further supplies of the elements which go to make up its tissues.

Classes of Food.

All organisms consist mainly of *carbon compounds*. For this reason, the study of carbon compounds, which is a very important branch of chemistry, is called *Organic Chemistry*. As one would expect, nearly all foods are organic substances—that is, carbon compounds. They fall into three main classes, called *Carbohydrates*, *Fats* and *Proteins*. We shall consider each of these classes in turn.

Carbohydrates.

These substances, of which sugar is an example, are all composed of carbon, hydrogen and oxygen, the two latter elements in the same proportions (two atoms of hydrogen to each atom of oxygen) as they are in water. These facts are summarized in the name carbohydrate (Latin: *carbo*, carbon. Greek: *hydro*, water). All carbohydrates, when strongly heated, decompose into carbon and water-vapour: the process is called "charring".

The *sugars* are the simplest carbohydrates, and contain either six or twelve carbon atoms in each molecule. Those with six are called *monosaccharides*, $C_6H_{12}O_6$. Examples are *glucose*, also called dextrose or *grape-sugar*, and *fructose*, also called lævulose or *fruit-sugar*. Sugars with twelve carbon atoms are called *disaccharides*, $C_{12}H_{22}O_{11}$. Examples are *cane-sugar* (*sucrose*) and *malt-sugar* (*maltose*).

All the sugars mentioned above are found in varying quantities in green plants, which make them from carbon dioxide and water: and they may also be found in animals, which have either absorbed them ready-made in their food or formed them during a stage in the breaking-down of more complex carbohydrates.

The uses of sugar as food are: to provide energy when broken down; to form the "bricks" from which the organisms can build up more complex foods, and then new tissue-material; to alter the concentrations of solutions in various cells, and so control the movement of water in the organism (page 87).

The presence of sugars in tissues can be detected by chemical tests. Sweetness of taste is not a reliable guide, because some sugars are not very sweet, and in many cases the sweetness may be masked by the strong taste of other substances in the tissue. Besides, some other substances which are not sugars also taste sweet (glycerine, for example).

INQUIRY 24. Chew a small piece of the bulb of a young onion. It contains quite a lot of sugar (as can be proved by other tests), but the strong flavour makes it difficult to detect the sweetness.

INQUIRY 25. Add a few drops of Fehling's solution to a little glucose solution in a test-tube. Heat it gently. The blue colour slowly changes to a muddy green, then yellow: and finally a red solid forms in the solution.

Repeat the test with a solution of cane-sugar. The solution remains blue; that is, the test does not work. Now try it with cane-sugar solution which you have boiled for a few minutes with a few drops of hydrochloric or sulphuric acid. This time the test works.

The chemistry of Fehling's test is rather complicated, but we may observe the following points about it:

The blue colour of fresh Fehling's solution is due to the presence of copper sulphate ($CuSO_4$). Sugars, except cane-sugar, have the property of converting this substance to red copper oxide by a chemical process called *reduction*. There are other substances with this property, but they are not commonly found in organisms. Cane-sugar is not a *reducing sugar*, but it can be converted into a mixture of other sugars, which are reducing sugars, by boiling it with an acid, or, inside organisms, by other means.

Starch is a more complex carbohydrate in which each molecule consists of a very large number of groups, each with the formula $(C_6H_{10}O_5)_n$, where the letter *n* stands for a large number. It is therefore called a *polysaccharide* (Greek: *poly*, many).

Starch is formed in plants from sugar. Its main use as a food is to form a reserve. It is insoluble in water and so does not interfere with the working of the organism until it has accumulated in large quantities. When this happens, the organism changes it back into sugar and transports it away from the region of activity to a storage organ (page 101), where it is reconverted into starch or some other form of food reserve.

Animals do not form starch in the same way as plants, but form a substance called glycogen, or animal-starch.

The presence of starch is easily detected because it turns deep blue in contact with iodine solution.

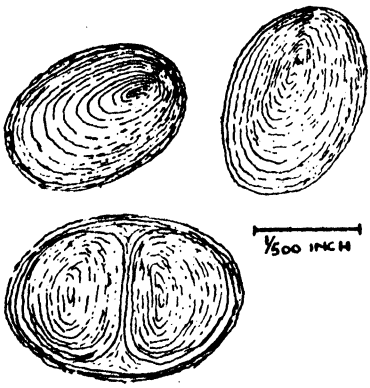


FIG. 34.—Grains of potato-starch.

INQUIRY 26. Cut a potato, or soaked bean, into two pieces, and put drops of iodine on the cut surface. A blue-black colour will show the presence of starch in the cells whose contents have been exposed by the cutting operation. The starch in the other cells is protected by the cell-walls and remains unaffected.

INQUIRY 27. Test small quantities of flour, tapioca, semolina, etc., with iodine.

Household starch is obtained from plants; the commonest sources are potatoes and various cereals such as wheat, rye and rice.

Flour consists almost entirely of starch, as do many of the staple foods of the world—rice, bread, potatoes, peas and beans, turnips, etc.

Cellulose, the material of which plant-walls consist, is a polysaccharide whose molecules contain more units than the molecules of starch. These units are in long chains, so that the molecules themselves are long and narrow; when interlaced they form a very tough structure: and when lying all in the same direction they form strong elastic *fibres*. As a result, cellulose finds many uses in *textiles*, such as cotton and linen, and in paper and cardboard. If the natural fibres are broken up by chemicals and mechanical pulping, the molecules can then be rearranged artificially by squirting a solution of them through fine holes or slits. The resulting material, when solidified, forms *artificial silk* threads, or sheets of *cellophane*.

Cellulose is of little use as food, except to bacteria. Animals cannot digest it; but many herbivorous animals have, in their intestines, colonies of bacteria which break down the cellulose into simpler compounds which can then be digested by the animals. Because of its resistance to digestion, cellulose adds bulk to the food of animals and so provides exercise for the muscles of the stomach and intestine (page 130).

Tests for cellulose are difficult to devise because the substance is not chemically very active. It is well known, for instance, that cotton and artificial silk have to be specially treated before they will "take" a dye.

INQUIRY 28. Test a piece of cotton-wool with iodine. No blue colour is seen. Drop a little concentrated sulphuric acid on the cotton-wool. It now turns blue with iodine, probably because a little of it has been broken down into starch molecules.

There are other carbohydrates besides the ones described above, but enough has been said to give a good idea of the class as a whole.

Fats.

There is a large group of food-substances whose molecules contain carbon, hydrogen and oxygen, but the last two elements are not present in the proportion of two to one as they are in the carbohydrates. These substances are *oils* and *fats*. In both, the proportion of hydrogen atoms to oxygen atoms is greater than two to one, and fats contain a greater proportion of hydrogen than is present in oils. This makes the fats solid at ordinary temperatures, while the oils are liquids. There is very little difference in their chemical properties.

Green plants build up oils from carbohydrates, especially when making seed. The oils are less dense than starch, and so are especially useful in seeds which have to be dispersed by the wind (page 266). The oils are insoluble in water, and so do not affect the osmotic pressure of the seed's tissues. This is important, because if the seed were to absorb water (page 163) before it was ready to germinate it would become liable to attack by moulds, fungi and bacteria.

Fats are rarely found in plants, a well-known exception being the cocoa-seed, which yields a fat called cocoa-butter.

Animals obtain their fats either from other animals (in their food), or by converting carbohydrates. Fishes often accumulate large quantities of oil (cod-liver oil, halibut-liver oil). Mammals and birds store fats in various parts of the body, often just under the skin (whale-blubber, for example).

> INQUIRY 29. Notice how much less prominent is the Adam's apple in a girl's throat than in a boy's. This is because girls normally have more fat just below the skin than boys have.

A quantity of *fat is a much more efficient store of energy than the same weight of carbohydrate.* When oxidized, the fat gives off more than twice as much energy as the carbohydrate. Oils and fats are therefore in great demand as foods in cold weather.

Eskimos consume large amounts of oil. The layer of fat beneath the skin of mammals not only acts as a source of heat energy, but, being a poor conductor of heat, helps to prevent undue loss of heat from the body. Thus, girls are less sensitive to cold than boys; whales, which are mammals in spite of their appearance, are able to keep their blood at a higher temperature than their surroundings, even in icy water. Cattle are fed on oil-cake in winter, and many oils are used as foods, especially in foreign lands.

British and American people are not very fond of oily foods, and this has led to a great industry for converting oils into fats by combining them with more hydrogen. *Margarine* and artificial cooking-fats are made from whale-oil, fish-oil, and oil from plants. Much of this oil is obtained from *ground-nuts* (also called monkey-nuts): and the cultivation of these has been developed on a very large scale in Africa. An American scientist, George Washington Carver, has developed over three hundred uses for pea-nuts, as they are called in America.

Apart from their use as food in organisms, oils and fats also carry round the body many important substances which, being insoluble in water, could not otherwise be conveniently carried by the blood. Some of the vitamins (page 78) are examples of these oil-soluble substances.

The simplest, and perhaps the best, test for oils and fats is that they make a lasting translucent mark on paper. Water makes a translucent mark, but the mark disappears in a short time when the water evaporates.

INQUIRY 30. Cut a castor-oil seed, or sunflower seed, and rub the cut surface on paper. It will leave a dark stain, but when held up to a bright light it will be seen that the light comes more easily through the stain than through the rest of the paper. A similar stain is made when butter, bacon, coffee, or other greasy food is wrapped in paper.

INQUIRY 31. Oils and fats produce a black colour when added to osmic acid solution. They also readily absorb the red dye, Sudan III. When burned, they give off blue smoke and an acrid smell.

Proteins.

The most complex food-chemicals of all are called proteins. The molecule contains carbon, hydrogen, oxygen, and, in addition, the element *nitrogen.* Some proteins also contain sulphur, phosphorus and metals.

Protein molecules are very large by comparison with inorganic molecules. The protein in white-of-egg has the formula $C_{239}H_{389}O_{78}N_{58}S_2$. Every organism contains in its protoplasm several different types of protein, which may not be found in any other organism. If all the water is removed from an animal then about five-sixths of what remains is protein.

Protoplasm is built up mainly from protein molecules and, as we should therefore expect, the chief use of *protein* in organisms *is for the growth and repair of tissues.* It has already been stated that every organism seems to have its own kind of protoplasm. This is because of the almost infinite number of ways of arranging the atoms in protein molecules. A great deal of reorganization of protein molecules goes on during digestion. Plants build up their proteins from carbohydrates and mineral salts.

Animals obtain proteins in their food and remodel them for their own use.

Tests for proteins depend on their chemical properties, but must be carefully applied, because no single test is *specific*; that is, other substances may respond to the tests while some proteins will not respond to all the tests.

INQUIRY 32. Place a test-tube containing a little raw egg-white in a beaker of water. Heat the water and observe how the egg-white becomes solid. This is *coagulation,* and occurs with two kinds of protein called albumin and globulin.

Now remove the test-tube, dry the outside, and heat it strongly in the bunsen-flame. The boiled egg-white chars (turns black) and gives off a smell like burning flesh. The smell is typical of proteins.

INQUIRY 33. Burn feathers, finger-nail clippings, and hair, and note the smell. Test the fumes with red litmus. A blue colour shows the presence of an alkaline substance, which by other tests can be identified as ammonia. (The old name for ammonia is "spirits of hartshorn", which gives a clue as to its origin.)

Heat a substance known to contain protein with soda-lime in a hard-glass test-tube. Ammonia is produced, and may be recognized by its smell, its action on litmus paper, or by holding near it the stopper of a bottle of concentrated hydrochloric acid (white fumes).

INQUIRY 34. Heat a protein-containing substance with a little concentrated nitric acid. A bright yellow colour appears, like that which the acid causes when spilled on the skin. When cool, add a few drops of ammonia solution. The colour changes to orange. This is the *Xanthoproteic* test. It is fairly specific, but gelatine, which is not a protein, gives the same results.

The unpleasant smells given off by decaying plants and animal remains are mainly due to the decomposition-products of the proteins in them. Thus, the smell of bad eggs is from the gas, hydrogen sulphide, formed by the breaking-down of sulphur-containing proteins.

Nitrogen and Life.

Proteins are indispensable to the formation of protoplasm: and as all proteins contain nitrogen this element is of vital importance to all organisms.

Nitrogen is a gas forming four-fifths of the atmosphere. It is an element which forms active compounds but is itself very inactive. Its value in the atmosphere, for example, is mainly to dilute the oxygen. Small amounts of nitrogen do, however, combine with the oxygen of the atmosphere during thunderstorms, and the compounds dissolve in rain.

Because of the difficulty of causing atmospheric nitrogen to form compounds, plants normally obtain their nitrogen compounds from the soil, in the form of nitrates. In the normal course of events the nitrates are reformed during the decay of the plants after death, and returned to the soil If, however, the plants are carried away by animals or Man from their place in the soil, that particular patch of ground has lost its nitrates, and if the process is repeated over a long period, the ground will become barren (incapable of supporting life).

There are many factors which take part in the circulation of nitrogen compounds. In an uncultivated region a balance is set up between those which enrich the soil and those which impoverish it. This balance is called the Nitrogen Cycle.

The Nitrogen Cycle—I.

We may assume that any patch of soil on which plants first appear contains mineral nitrates: that is, compounds of metals with nitrogen and oxygen. Examples of these are sodium nitrate, $NaNO_3$, and potassium nitrate, KNO_3. Green plants growing in the soil absorb these compounds dissolved in water through their roots. When the plants die they are attacked by *putrefying bacteria*, which are themselves plants but have no chlorophyll and live on the remains of green plants. These bacteria break down the proteins in the green plants in different ways. Some of them release the nitrogen in the form of ammonia gas, NH_3, which may either combine with salts in the soil or escape into the air. Some of the nitrogen is lost into the atmosphere by this escape of ammonia.

If the ammonia combines with salts such as calcium carbonate it forms ammonium compounds, and these are converted by other bacteria, first into nitrites and then into nitrates; these are then ready for absorption by other green plants. The bacteria which work in this way are *nitrifying* bacteria.

Unfortunately, there is another class of bacteria, the *denitrifying* bacteria, which destroy nitrates in the soil by converting them into free nitrogen, which is lost into the air. The activity of these "saboteurs" is balanced by the *nitrogen-fixing bacteria*, which alone among plants are able to convert atmospheric nitrogen into useful nitrogen compounds. Some of the nitrogen-fixing bacteria live in colonies on the roots of plants of the clover, pea and bean family (leguminous plants). The roots of these

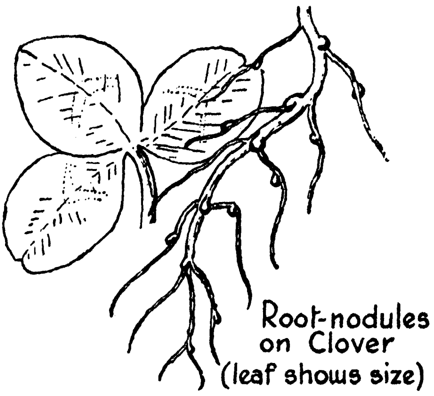


FIG. 35.

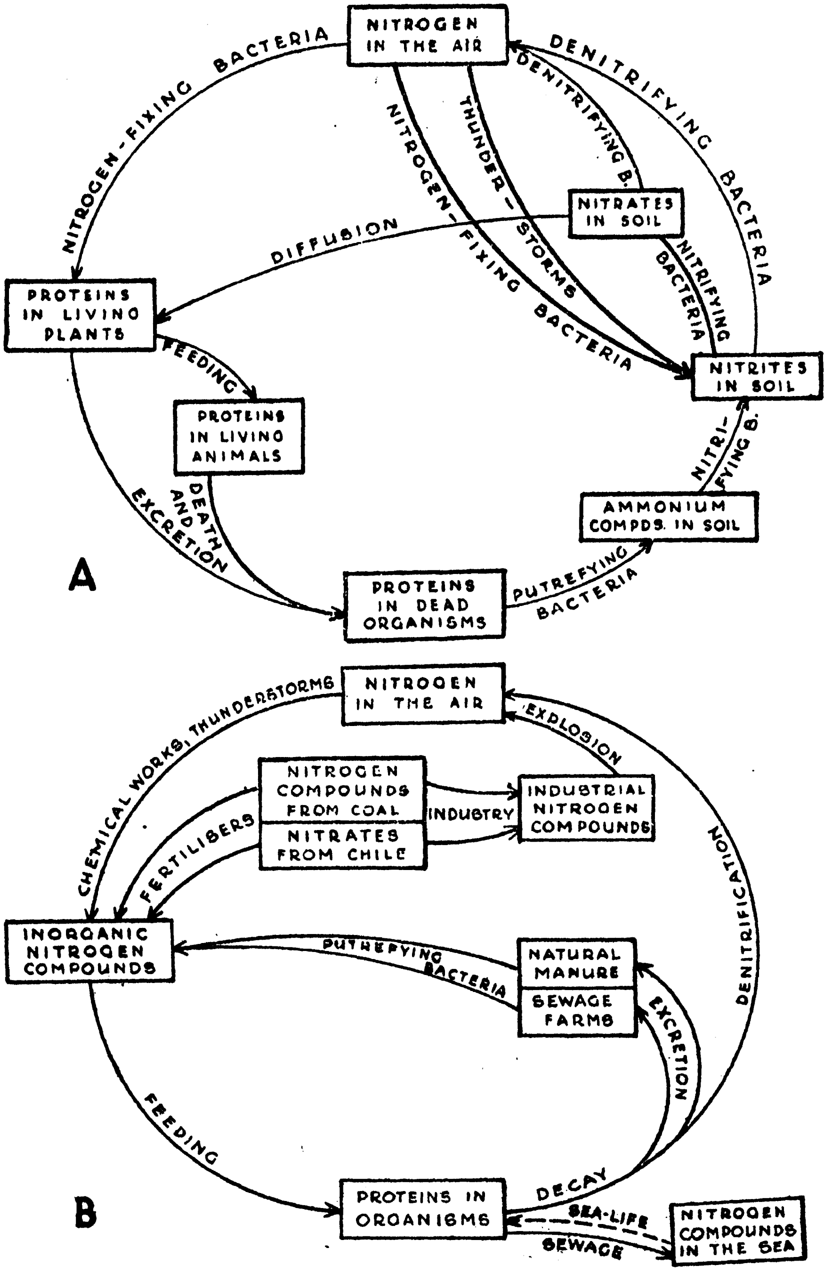


FIG. 36.—The Nitrogen Cycle.
A.—In Nature. *B*.—As influenced by civilization.

plants are covered with little swellings (*nodules*), each packed tight with millions of bacteria. The plant absorbs the nitrates made by these bacteria in return for the protection it affords them.

Animals which eat the plants return most of the nitrogen compounds to the soil, either in the form of natural manure, or as decomposition-products of their bodies after death.

The diagram (Fig. 36) summarizes this complicated story, as it appears when allowed to proceed undisturbed by Man. When Man takes a hand the story becomes even more involved.

The Nitrogen Cycle—II.

On a farm, the natural operation of the nitrogen cycle is interfered with by Man. In the first place, by continually removing crops from the soil the store of nitrates is greatly depleted, and special steps have to be taken to restore them if the quality of the crops is to be kept up.

The steps taken are:

(*a*) *Rotation of crops*, "ploughing-in" of leguminous crops, and the "fallow" system. In all these cases, the object is to enable the ground to recover its fertility by the natural activities of plants.

By growing different crops in rotation, plants which make heavy demands on certain elements, including nitrogen, are grown only at intervals instead of robbing the same areas of those elements every year.

This system, combined with the fallow system, was used in this country as long ago as the tenth century. The Anglo-Saxons used to grow wheat one year, oats or barley the next, and for the third year the ground was left "fallow"—that is, no crops were sown on it. In later years a more scientific rotation made it possible to dispense with the fallow system.

Ploughing-in of leguminous crops has been practised for centuries, but it was only when the microscope made it possible to investigate the contents of the root-nodules (see above) that the reason for its effectiveness was discovered. Other crops, such as mustard or lupins, which are quick-growing, are often ploughed in to enrich the soil. This is known as "*green-manuring*".

(*b*) The use of *natural manure*, and of *artificial fertilizers*. The waste products of animals are very rich in nitrogen compounds. By their aid these compounds are transferred from grazing-land to crop-land, where they are of greater value.

There are great deposits of nitrates in Chile which make valuable fertilizers. They are, of course, not inexhaustible, and when they have all been used up a very serious agricultural problem will have to be faced.

Another valuable source of nitrogen compounds is the *excreta* (waste products) of sea-birds, which accumulate to a remarkable extent on many oceanic islands. Strictly speaking, this "guano", as it is called, is a natural product, but from the point of view of the farmer, who buys it after it has been processed by manufacturers, it is an artificial manure. In the same way, such substances as fish-meal and dried blood are used as fertilizers, especially in small gardens.

Unfortunately, there are many other industries besides agriculture which require large quantities of nitrates. Some of these are the manufacture of explosives for peace and war, artificial silk, and plastics. This vastly increases the drain on the world's nitrate resources.

On the other hand, some chemical processes, such as the manufacture of coal-gas, yield as by-products nitrogen compounds which can be used as fertilizers. In the last twenty-five years, chemical and electrical methods have been developed for turning atmospheric nitrogen into nitrogen compounds on a fairly large scale, but these processes are very expensive and are not yet sufficiently developed to weigh very heavily in the balance of nitrogen compounds.

The growth of large towns in the last hundred and fifty years, following the industrial revolution, has done a great deal to upset the balance. The sewage of these towns is usually tipped into the sea and lost, whereas it could provide huge amounts of fertilizers. Some towns are doing something to correct this by establishing *sewage-farms*, where the nitrogen compounds are recovered and returned to circulation, largely with the help of specially-cultivated bacteria.

Fig. 36B shows the effects of Man's intervention on the nitrogen cycle. It will be seen that the balance is no longer perfect. There is a steady leakage of nitrogen from its compounds into the atmosphere. This is a very serious loss, and scientists all over the world are busy devising methods of conserving nitrogen compounds, and making more from the air.

Other Elements in Food.

Protoplasm usually contains other elements, apart from carbon, oxygen, hydrogen and nitrogen. Plants absorb these other elements in solution from the soil, and the subject will be dealt with more fully in the next chapter. Animals obtain these additional elements by eating plants, or by eating other animals which have obtained them from plants.

The main elements concerned are the non-metals *sulphur*, *phosphorus* and *chlorine*, and the metals *sodium*, *potassium*, *magnesium*, *iron* and *calcium*.

Traces of many other elements are found in the tissues of most organisms. Iodine, for example, is essential to human beings, but only a very small amount of it is present in the body, in the thyroid gland (page 154).

Magnesium is required by green plants as it forms part of the molecule of chlorophyll. Animals with red blood require considerable amounts of iron, which forms part of the red colouring matter of the blood (*hæmoglobin*).

All animals need a continual supply of common salt (sodium chloride). In regions like Central Africa, where this commodity is scarce, men and animals will travel many miles to obtain it. At various times in history people have exploited Man's need for salt, either by taxing it or by supplying it to native populations in exchange for precious jewels, gold, and other valuable goods.

Bones consist mainly of calcium phosphate, $Ca_3(PO_4)_2$. The element phosphorus was for centuries obtained only from the waste products of animals. There is seldom a shortage of calcium in food, but where it occurs, or if the organisms are unable to extract it from their food, serious results follow, especially in vertebrate animals (page 79).

Vitamins.

It has been known for very many years that a diet consisting entirely of preserved foods often results in poor health. In the East, people who lived almost exclusively on rice were found to develop a disease called beri-beri, unless they included in their rice some of the husks of the seed. Chemical analysis of milk makes it possible to build up, or synthesize, artificial milk. Rats fed on this milk were found to waste away, but if only a few drops of natural milk were included they developed normally.

All these apparently unrelated facts, and many others, after a vast amount of patient research by doctors and scientists, led to the discovery that, although food is made up of the substances described in the last few pages, animals cannot make use of it and live a healthy life unless it contains very small traces of certain special chemicals. These are present in such small amounts that ordinary chemical analysis fails to detect them. Sir Frederick Gowland Hopkins (1861–1947), who invented the word "vitamin", worked out that one ounce of Vitamin D would protect 1,000,000 children from rickets for a whole year.

It will be seen that the plants provide most of the vitamins (Fig. 37), and this explains why a diet containing fresh vegetables seldom needs helping-out with deliberate doses of vitamins. Vitamin D is peculiar in that it can be manufactured in the human body (under the influence of ultra-violet light from the sun or from artificial sources), from a chemical in the skin called ergosterol. A by-product of the process is the brown colouring of the skin known as "sun-tan".

Vitamins are in general unstable (easily destroyed). They are therefore destroyed by most methods of preserving food, and they cannot be stored in the body. Thus, it is useless to take large doses of them in the hope that they will last for a long period.

Milk: the Complete Food.

The highest class of animals, the vertebrates, are entirely dependent on their mother's milk for the early stages of their life. Milk must therefore be a perfect food. Different animals have milk of slightly different composition, so it cannot be assumed that milk from one type of mammal is a perfect food for

VITAMINS

NAME	SOURCES	EFFECTS	PROPERTIES
A	Fish-liver oils, fats, green and yellow vegetables and fruits, esp. carrots.	Stimulates growth, prevents infection of eyes and mucous linings in the body.	Made only by animals, from their food. Oil soluble. Destroyed by heat.
B_1 (Aneurin)	Husks of cereals, yeast, meat, egg-yolk, peas and beans.	Prevents and cures inflammation of nerves, "beri-beri" and other nervous diseases.	Soluble in water. Destroyed by heat or soda.
B_2 (Riboflavin)	As above.	"Beauty-vitamin." Prevents skin-blemishes, and the disease, pellagra.	Unaffected by cooking or preserving. Soluble in water.
C (Ascorbic acid)	Oranges, lemons, grapefruit, raw cabbage, tomatoes, black currants, rose-hips.	Prevents scurvy, irritability and proneness to infection.	Unstable: destroyed even by finely shredding vegetables. Water-soluble.
D (Calciferol)	Animal fats, except pig-fat. Fish-oils. Made under human skin in sunlight.	Prevents and cures malformation of bones and teeth as in rickets.	Very stable; survives cooking and preserving. Soluble in oil.
E	Whole cereals and green vegetables.	Not fully understood. Promotes fertility in rats.	Stable to heat, destroyed by oxygen. Oil-soluble.
K	Green vegetables.	Prevents excessive bleeding by coagulating the blood.	May be made in intestine by bacteria.

FIG. 37.—Table of Vitamins.

another type. Cow's milk, for instance, contains too much fat and too little sugar for human babies; these two factors are, however, easily adjusted to make the milk suitable for infants.

As mammals grow older, their digestive systems adapt themselves to dealing with solid food: and if they do not get the solid food their development is held up. The diet of older animals, therefore, contains considerable amounts of roughage, or indigestible material, on which the muscles of the digestive system can exercise themselves.

Water in Organisms.

All organisms, except the seeds of plants, contain a high proportion of water. The comparative dryness of seeds makes them useful as concentrated food.

It has been said, truly if not reverently, that even an archbishop is sixty-five per cent water. This figure is about average for the vertebrate animals. In plants, the proportion is often much higher. These facts are easily observed by comparing the weight of organisms when alive with their weight when desiccated (gently but thoroughly dried by heating).

> INQUIRY 35. Weigh a frog alive. Kill it with chloroform and keep it dry and warm (e.g. near a radiator) for a week. Weigh it again and find what fraction of its live weight was water.
>
> INQUIRY 36. Weigh a sliced onion, keep it in a warm place till quite dry, and weigh again. Find what fraction of it was water.

Animals acquire water with their food, either as free water or in combination, as part of the food-molecules, to be liberated and recombined as required.

In addition to its part in the mechanical structure of organisms (page 188), water plays many other important roles. It provides the means of:

(*i*) transporting food and other material, from place to place in the organism (human blood is nearly ninety per cent water; plant-sap has often an even higher proportion of water);

(*ii*) enabling the body to rid itself of useless and harmful substances: this process is called *excretion*;

(*iii*) controlling the temperature of the organism.

Excretion.

At the beginning of this chapter it was said that organisms require a means of ridding themselves of useless or harmful substances. This is not so vital with plants because they are very selective in their absorption of chemicals. The only substance they absorb in greater amounts than they can use is water, and they give this off again in transpiration (page 30).

Animals, being unable to make their own food, have to absorb many substances which they cannot retain permanently. The solids are driven out from the body with a little water (about ten per cent). Those substances which are soluble in water are either excreted through the skin (*perspiration* or *sweating*), or through a special excretory system. The higher animals use all these methods.

Human perspiration contains various organic compounds, and some common salt. It is given off by special sweat-glands in the skin (page 58).

Temperature Control.

It is a well-known fact that when a liquid evaporates it absorbs heat from its surroundings. The ancients kept drinking-water cool by storing it in unglazed earthenware vessels, so that some of it seeped through the pores and evaporated, cooling the rest. Housewives keep milk and other foods cool by covering them with muslin which dips in water.

Organisms avoid overheating by giving off water-vapour from their surfaces. Transpiration and perspiration therefore serve a dual purpose: excretion and temperature-control.

INQUIRY 37. Warm some water to body-temperature (about 37° C.). Dip one hand in it, and wave both hands through the air. The wet hand will feel colder than the dry one, though both are at the same temperature originally.

INQUIRY 38. Spread a small cloth (a handkerchief) on the bench and pour water on a part of it. This part will feel colder to the touch than the rest. (This effect is partly due to increased contact.)

It is well known that men who work in very hot surroundings must drink large quantities of liquid. Otherwise they will stop sweating, become overheated and collapse.

The difference between a desert and a jungle lies not so much in the heat of the sun but in the lack of moisture in the desert, so that any plants which grew would quickly shrivel up through being unable to control their temperature by transpiration.

Balance of Food in Nature.

The facts described in this chapter emphasize the remarkably fine balance between the feeding processes of plants and animals. The animals could not survive without the food made by the plants; the plants use up the carbon dioxide given out by animal respiration, and contribute oxygen to the atmosphere. The nitrogen cycle shows how far-reaching an apparently minor interference can become. We shall continually meet more examples of this intricate balance as we learn more about the lives of organisms, but already it must be obvious that Life as a whole is no thing of chance; it works to a huge plan. The greater the plan the greater must be the intelligence of the planner. So far we have only touched the fringe of the plan which governs the relations between organisms.

Balanced Human Diet.

The main uses of food in organisms can be summarized as (*a*) to provide energy, (*b*) to enable the organism to grow to its full size, and (*c*) to provide for the replacement of worn tissues.

It will be noticed that proteins fulfil all these requirements, while fats and carbohydrates fulfil only the first, and perhaps to a small degree in the case of fats, the second. One might expect, therefore, that it would be possible to live on proteins alone; but this is not the case. The digestive system of a mammal is a complex mechanism, very delicately balanced. It requires the three classes of food in fairly definite proportions if it is to function properly.

The following table gives a sample of the requirements for a day's balanced diet for an average adult man doing light work.

CLASS OF FOOD	WEIGHT	PROPORTION	CALORIES
Carbohydrate	360 gms.	3	1,450
Fat . .	120 „	1	1,060
Protein . .	120 „	1	490
Total . .	600 gms.	5	3,000

Thus, three-fifths of the diet should be carbohydrate, one-fifth fat and one-fifth protein. In addition, there are many other requirements, such as vitamins, mineral salts, water, etc., which may or may not be present in sufficient amounts in the above foods. Certainly some water, at least, will have to be taken separately, usually in the form of beverages such as tea, coffee, wine or beer. About three pints of water should be taken each day.

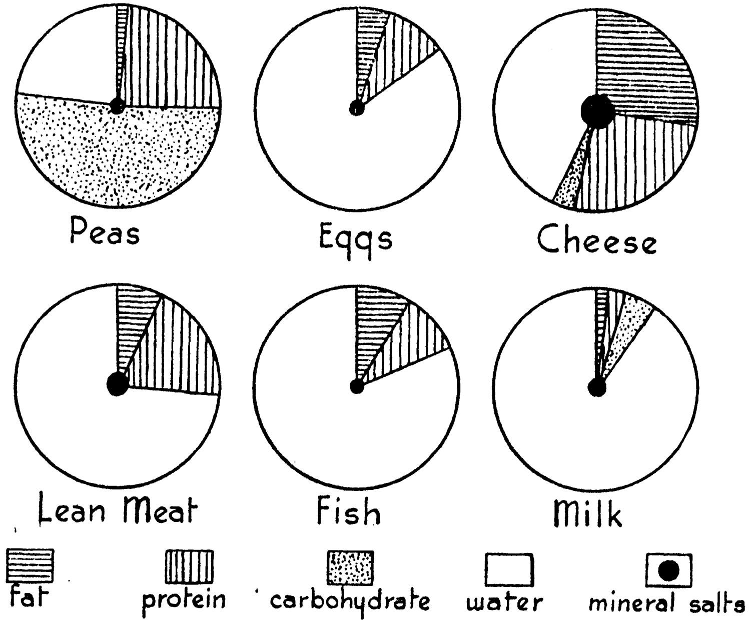


FIG. 38.—Composition of some common foods.

QUESTIONS

SECTION A.

1. Compare the uses of carbohydrates, fats and proteins as foods.
2. Draw up a menu for a day's meals, to provide a properly-balanced diet for one day for an average adult.
3. Describe the simple tests for (*a*) a reducing sugar, (*b*) starch, (*c*) fat, (*d*) protein, stating in each case what you would use as a sample.
4. Why are seeds so much used for human food? Name six seeds so used.
5. Explain the importance of bacteria in the feeding of plants and animals.
6. Where do wild animals get their vitamins? Explain why children living in slums are more likely than country children to suffer from rickets.
7. Write an essay on the nitrogen cycle.
8. Why does hard work cause a man to sweat? Describe what benefit he gains from the process.

SECTION B.

1. Discuss the properties of (*a*) carbohydrates, and (*b*) fats, which make them suitable for use as animal foods.
2. Write an essay on the effects of the last war on the nitrogen cycle.
3. Why does the Ministry of Food recommend that all babies should be given cod-liver oil and orange-juice from birth?
4. Describe the benefits and dangers of a turkish bath.

CHAPTER VI

HOW PLANTS WORK—I.

HAVING seen in previous chapters something of the structure of plants we can now build up a connected account of how they work. Some aspects of their work have been referred to already, because it is important to realize that the *structure* and *functions* of organisms are very closely related. It is almost impossible to describe the structure of an organism without making at least a passing reference to its function: and to try to do so would result in a distorted idea of the organism as an individual.

Water in Plants.

The smallest plants, such as the filamentous (thread-like) plants (page 196), absorb their water supplies through the whole surface. Some plants using this method can reach a considerable size, as in the case of many algæ (page 200); but usually large plants have a definite root system through which they absorb water and salts. The complexity of this system ranges from the presence of a few specialized hairs on the underside of the plant (liverworts), to the elaborate root structure of the flowering plants already described.

The method of absorbing water and salts is very complicated, but has some features which are easily understood. It depends on two processes which are related, but are best considered as quite distinct from each other.

Diffusion and Osmosis.

Fresh air is a mixture (not a compound) of gases, consisting of one-fifth oxygen, nearly four-fifths nitrogen, three parts in a thousand of carbon dioxide, one part in a hundred of the inert gases, and some water-vapour. Now, although carbon dioxide is nearly forty times denser ("heavier") than helium, which is one of the inert gases, we do not find all the carbon dioxide near the ground, and all the helium up in the sky. In fact, any sample of fresh air will be found to contain all the gases mentioned above, in almost exactly the proportions listed. This is because, when several gases which do not react chemically, are present in the same space, each gas spreads itself through the entire space.

> INQUIRY 39. Fit a test-tube with a cork and delivery tube leading to the bottom of a tall gas-jar. In the tube place a few copper turnings, pour on a few cubic centimetres of concentrated nitric acid, and lead the brown fumes into the jar. When the bottom of the jar is quite brown with the gas, remove the delivery tube from it and cover the jar. In about ten minutes' time it will be seen that the brown gas has spread throughout the jar, in spite of being "heavier than air".

This process of mixing is called *diffusion*, and takes place also with solutions.

> INQUIRY 40. Pour into a tall gas-jar enough water to leave about an inch of space at the top. Place a thistle-funnel in the water and pour gently down it, making as little disturbance as possible, about twenty cubic centimetres of deep-blue copper sulphate solution. Leave the jar for a few days, when the liquid will be found to have a uniform pale-blue colour, although copper sulphate is denser than water.

Diffusion may be defined as the movement of a substance from a region where it is in high concentration, to one of lower concentration. It is brought about by the continual natural movement of the molecules, and is independent of gravity. It will take place through a partition or membrane provided the membrane contains holes, each large enough for at least one molecule of the substance to pass through. Thus it is possible to separate two substances dissolved in the same liquid by placing them in a tray whose pores are bigger than the molecules of one substance, but less than those of the other, and floating the tray in a bath of the solvent liquid.

A membrane allowing dissolved solids to pass through is a *permeable* membrane.

Some membranes will allow the solvent liquid of a solution to pass through them, but not the solids which are dissolved in the liquid. Such a membrane is *semipermeable.* The protoplasm lining the walls of cells is semipermeable.

The passing of a solvent through a semipermeable membrane is called *osmosis*, and it takes place in both directions, but at different rates, so that it tends to equalize the concentrations of solutions on the two sides of the membrane. In organisms, the solvent is nearly always water, so we can define osmosis as the passing of water through a semipermeable membrane, from one solution into a more concentrated one. Notice that this definition only expresses the net result of the movement in both directions.

INQUIRY 41. Tie a piece of pig's bladder firmly over the end of a tube about ¾″ wide and 3″ long (a test-tube with the closed end cut off). Fill the tube with golden syrup and insert a one-holed rubber stopper carrying a long piece of glass tubing (Fig. 39), taking care to avoid including air-bubbles. Wash away the syrup on the outside, and support as shown in a beaker of water. Mark the level of the syrup in the tube with a strip of gummed paper, and set the experiment aside for a few days, noting the rising level as water enters through the membrane.

Osmotic Pressure.

Cell-sap, though itself a dilute solution, is more concentrated than soil-water solution (page 91), so water passes from the soil into the roots of plants by osmosis. The pressure which drives the water through the membrane is called *osmotic pressure.* In the root it is partly counteracted by the *internal pressure* of the cells, which can best be compared to the resistance offered by the elastic wall of a balloon when it is blown up. The remaining inward pressure, after allowing for this internal pressure, is called *root-pressure.*

INQUIRY 42. Cut off the entire shoot of a garden geranium or fuchsia about two inches above the soil. Bind on to the stump, with rubber tubing and twine, a piece of glass tubing about a foot long, and the same width as the stump of the shoot. Pour down it about two cubic centimetres of water and two of paraffin to prevent evaporation. Mark the level of the paraffin and leave the plant in a warm place. The glass tube will slowly fill with liquid owing to the root-pressure.

INQUIRY 43. Peel a potato round the middle, cut it in halves, and scoop out of each half a hollow as shown in Fig. 41. Boil one half for ten minutes, set both halves in a shallow dish of water, and place a spoonful of sugar in each of the hollows. The next day, the hollow in the living potato will be full of liquid.

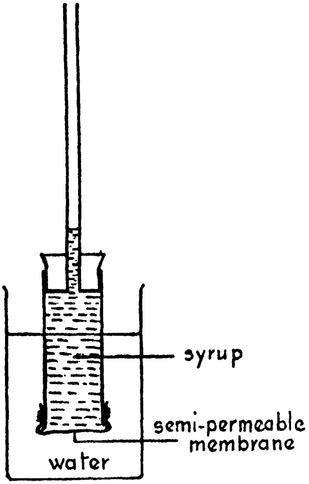


FIG. 39.—Osmosis.

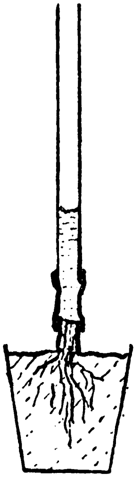


FIG. 40.—Root-pressure.

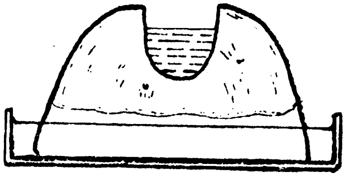


FIG. 41.—Showing osmosis through living potato.

The boiled potato is a control, to show that the difference in the results can only be due to the one factor that differs in the two halves, namely that the living potato has its cells (and therefore its semipermeable membranes) intact, while the other has had them ruptured by the boiling process. This rupturing of cells is one of the main advantages of cooking food. It enables the juices to escape and so improves the taste and makes the food more easily digested.

Control experiments should be performed whenever possible in biology as it is difficult to experiment on one feature of an organism without affecting others unknowingly. When a control is not described in the instructions for an inquiry you should try to devise one yourself.

When soil-water enters a root-hair, the cell-sap there becomes less concentrated than that of the inner cells of the root, so the water passes on by osmosis until it reaches the conducting vessels in the stele.

Salts enter the root at the same time, but by diffusion, as it is the *dissolved substances* in this case which are required by the plant. Salts are able to pass through a semipermeable membrane because, in solution, their molecules break up into smaller fractions, called *ions*; these are smaller than the pores of the membrane.

Osmotic pressure can be very powerful, and is responsible among other things for the fact that weeds sometimes force their way through concrete pavements. Other common effects of osmosis are the swelling of dried fruit when placed in water, and the pouring-out of juice from sliced fruit when sugar is sprinkled on it. A control for this could be performed by using sand, which is insoluble, instead of sugar.

> INQUIRY 44. Wash a slice of raw beetroot and one of cooked beetroot and place each in a saucer of water. The cooked slice will soon colour the water, while the raw slice does not.

Conduction in Plants.

When the water reaches the stele it begins to travel up towards the stem, and eventually reaches the leaves. This movement is caused partly by root-pressure pushing from below, partly by *capillarity* (the force which makes liquid travel up narrow tubes and through porous materials such as blotting-paper), and partly by *transpiration*.

> INQUIRY 45. Soften a piece of glass tubing in a bunsen flame and draw it out quickly till it is about the thickness of a cotton thread. Break it, and dip the narrow ends into ink. The ink will rise up the tubes.
>
> INQUIRY 46. Hold the end of a capillary tube full of water near a bunsen flame. The water will be drawn up the tube.

On a warm day a large plant such as a tree may lift up through its trunk and give off from its leaves many gallons of water per hour. The work involved is considerable, as you would realize if you had to carry the water in buckets to the top of the tree. The transpiration takes place through the stomata (page 32).

> INQUIRY 47. Place a piece of cobalt-chloride paper, which is blue when dry, on each side of the leaf of a growing geranium, holding them in place with microscope slides and a wire clip

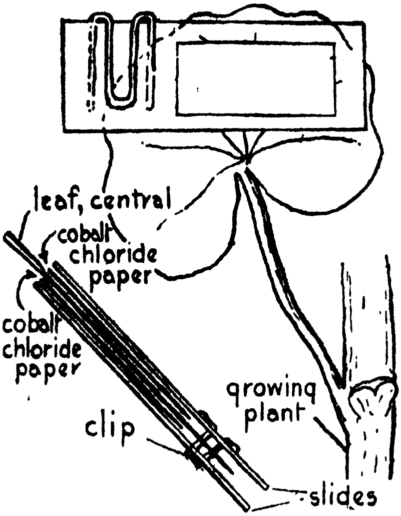


FIG. 42.—Testing transpiration.

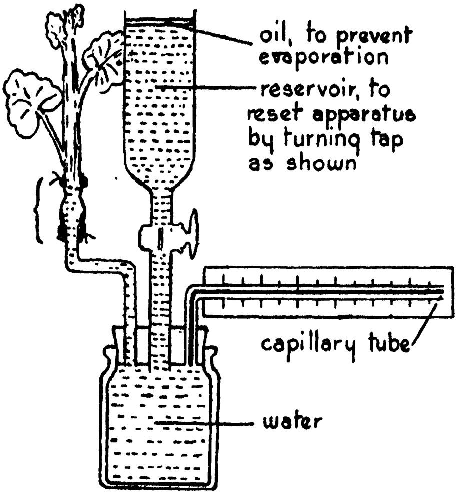

oil, to prevent evaporation
reservoir, to reset apparatus by turning tap as shown
capillary tube
water

FIG. 43.—Farmer's potometer.

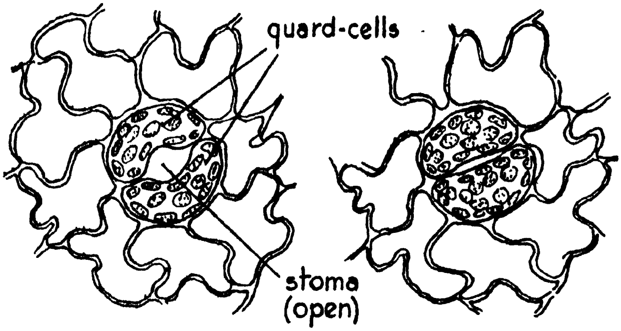


FIG. 44.—Action of stomata.

(Fig. 42). The paper on the underside of the leaf will turn pink before the other, showing that more moisture is given off from the underside, which contains nearly all the stomata.

INQUIRY 48. The rate of passage of water through a shoot is measured by a *potometer* (Latin: drink-measurer) as seen in Fig. 43. The shoot to be tested should be cut from the plant and kept in water for half a day, and the last two inches or so of the cut stem again removed just before setting it up in the apparatus.

How Stomata Work.

On page 32 it was stated that stomata regulate the exchange of gases and water-vapour by changing their shape. Fig. 44

shows how they do this. The guard-cells contain chloroplasts and so are able to make sugar and starch. Their walls are of different thicknesses in various places, so that when full they bulge in a way which opens the pore between them. The amount of water in the guard-cell is controlled by the inter-conversion of sugar and starch. When the pore is to open, a strong sugar-solution is formed, which attracts water by osmosis from surrounding cells. When the pore is to close, some of the sugar changes to insoluble starch, which lowers the concentration of the cell-sap, and water leaves the guard-cells, allowing them to collapse and close the pore. Light-intensity controls the changes.

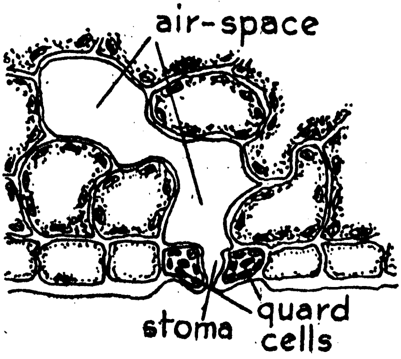


Fig. 45.—Sectional view of stoma.

> Inquiry 49. A good illustration of the action of guard-cells is given as follows: split the flower-stalk of a daffodil lengthwise, and tie two three-inch pieces of it "back-to-back" at the ends with thread, after soaking in salt water to make them limp. On placing this model stoma-with-guard-cells in fresh water it will open, and will close again when replaced in salt-solution.

Minerals in Plants.

So far we have been concerned with the water-supply of plants; but it must be remembered that the plant obtains from the soil all the elements it needs, except oxygen for respiration, and carbon. The elements in the soil-water are present as solutions of salts. A salt molecule contains a metal and a non-metal element or group of elements. The most important elements for plants are potassium, magnesium, calcium and iron. The most important non-metals are nitrogen, sulphur and phosphorus.

A solution containing all these elements is called a *normal culture-solution*, and is made up as follows:

Potassium nitrate	1.0 gram
Potassium phosphate	0.5 gram
Calcium sulphate	0.5 gram
Magnesium sulphate	0.5 gram
Iron chloride	a few drops
Water (distilled)	1 litre

The effect on the plant when any of these elements is absent may be found by using the appropriate culture-solution; thus, potassium can be omitted by using calcium nitrate and phosphate; calcium by using potassium sulphate, and so on. Care should be taken in such cases not to introduce new elements when substituting, because then it would not be clear whether the changed results were due to the lack of one element, or the introduction of the other.

The absence of potassium, nitrogen, phosphorus, or sulphur prevents correct protein-formation, so the plant cannot grow. Lack of calcium results in poor formation of cell-walls. If magnesium or iron is absent no chlorophyll is formed. It is interesting that iron is necessary for the formation of chlorophyll, although there is no iron in its molecule. The iron takes part in one stage of the formation and slips out again at a later stage. This explains why so little iron is needed.

Other elements are often present in plants—silicon in grasses, iodine in seaweed, etc. It has recently been discovered that many plants cannot live without extremely small amounts (traces) of manganese, boron, zinc and copper. It may be that enough of these elements is present in the seed to enable the plant to survive if it fails to get them from the soil: but its own seeds will then be deficient in these elements, and the species would gradually die out unless supplies of the "trace-elements" were renewed.

Respiration of Plants.

Plants, like animals, breath in oxygen and breathe out carbon dioxide. Experiments to prove this must be designed to prevent interference by photosynthesis. This is easily done by keeping the plants in the dark, where the latter cannot take place.

INQUIRY 50. Plunge a lighted taper into a bell-jar which has been kept in the dark for twenty-four hours. The taper goes on burning. This is the control experiment. Now place a growing plant in the jar, close it and leave it in the dark for a further twenty-four hours. On testing with a lighted taper the light immediately goes out, showing that the oxygen has been removed from the bell-jar by the plant.

INQUIRY 51. Carbon dioxide turns lime-water milky. In the apparatus shown in Fig. 46, air is made to pass through lime-water, then into the bell-jar containing the plant, then through more limewater. The second bottle of limewater becomes much more milky than the first, showing that the plant has discharged carbon dioxide into the air.

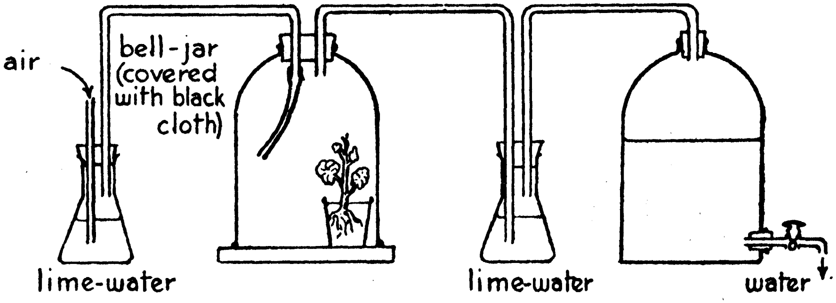


FIG. 46.—Carbon dioxide produced during respiration.

INQUIRY 52. Caustic potash absorbs carbon dioxide, which can be released from it again by adding dilute acid. Fit up the apparatus shown in Fig. 47, along with a duplicate set. Into one place some germinating peas, and into the other a similar number which have been killed by boiling for a few minutes (a little phenol will prevent the dead peas from going bad). The living peas remove oxygen and give off carbon dioxide which is absorbed by the caustic potash. The water in the pressure-gauge rises, showing the reduction in the quantity of gas in the apparatus. After three days in

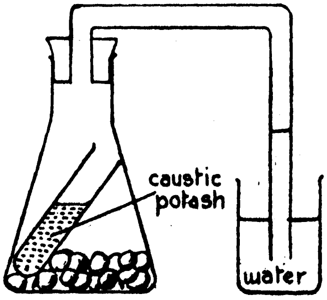


FIG. 47.—Germinating peas convert oxygen to carbon dioxide.

the dark, remove the two tubes of caustic potash, and add dilute acid to each. The one from the control will show no action, but the other will fizz and may overflow as the carbon dioxide is released.

Respiration Generates Heat.

It has been seen (page 59) that respiration releases energy. Some of this energy always appears as heat, but in plants this usually passes unnoticed.

INQUIRY 53. Place moist cotton-wool in a thermos flask and cover it with germinating peas. Place a thermometer in the flask and hold it in place with a wad of cotton-wool in the neck. Set up a control with killed peas. The temperature in the first flask will rise and remain above that of the control.

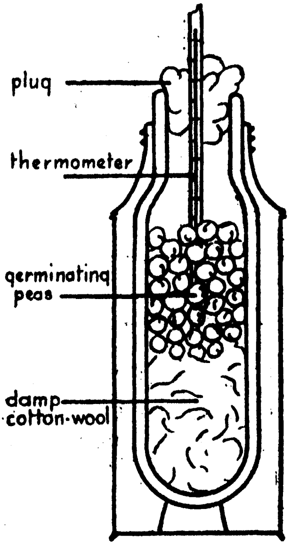


FIG. 48.—Respiration generates heat.

Even dry seeds respire, but the amount is very small as they do not carry out any activity apart from this. If kept in an atmosphere without oxygen for long periods, however, they will suffocate.

Anaerobic Respiration.

When a plant's oxygen supply is cut off it does not suffocate at once, because it is able to carry out a special type of respiration in which it obtains oxygen by breaking down its food reserves, or even its own tissues.

This is anaerobic (airless) respiration, and is probably just the first stage in the breaking down of food substances, and would normally carry on with the help of oxygen till only carbon dioxide and water were left.

In anaerobic respiration, the process stops at the early stage and often the partly broken-down food molecules at this stage are poisonous (alcohol, for example): so the process cannot be carried on indefinitely.

Some plants are able to survive much longer than others in this way, especially bacteria and other non-green plants, of which yeast is a well-known example (page 205). This is because they obtain their oxygen, not from within, but from sugary materials in which they float. These organisms are made use of in the preparation of alcohol, and in baking, where the carbon dioxide they give off blows holes in the dough, which is then "set" by the heat applied and so forms a food which is light in texture and easy to digest.

QUESTIONS

SECTION A.

1. Explain the difference between diffusion and osmosis. Describe an experiment to demonstrate osmosis.
2. Trace the course of water from the soil, through a plant, to the atmosphere, naming the processes by which it is transferred.
3. Give three reasons for the use of golden syrup in the experiment on osmosis. Name any other solution which could be used.
4. What is transpiration? Explain how it benefits the plant, and how it may be a handicap to it.
5. Why is it better to water a potted plant by standing it in a shallow dish of water rather than by pouring water on to the soil in the pot?
6. Name the elements essential for the growth of plants, and describe the effects of the lack of each of three of them.
7. Describe how it can be shown (*a*) that plants in the dark absorb oxygen, and (*b*) that oxygen is necessary for plants.
8. Describe the functions of the stomata in a green plant.

SECTION B.

1. Explain how plants can survive in soil which feels quite dry when handled, but may die if the soil becomes waterlogged.
2. Why does the continuous operation of osmosis in plants not cause the cells to burst? What would happen if a plant were dug up and its roots immersed in a strong solution of sugar and water?

3. Why is it that bean-plants (for example) of a considerable size can be grown simply by setting the seeds in moist insoluble sand and leaving them in a warm place? What happens if the plants are left in these conditions for a long time?

4. Describe the effect on the rate of transpiration of (*a*) a foggy day, (*b*) a frosty night, (*c*) an unusually hot sunny day, (*d*) an unventilated heated greenhouse.

CHAPTER VII

HOW PLANTS WORK—II.

ON page 9 it was seen that green plants are the only organisms able to carry out photosynthesis: that is, to build up complex organic compounds from carbon dioxide and water under ordinary conditions of temperature and pressure. We can now look a little closer at the mechanism of this process.

Carbon Assimilation.

The term Carbon Assimilation is in some ways an improvement on the older term, photosynthesis, because it emphasizes the fact that the outward signs of the process are the taking-in of carbon dioxide, and the giving-out again of all the oxygen so taken in, leaving the carbon (assimilated) inside the plant in the form of solid or liquid compounds. What happens to the carbon in the time between entering the plant and finishing up as part of a sugar-molecule is still not fully known, and many theories have been suggested. Here is an example.

It is possible in the laboratory to convert six molecules of a substance called formaldehyde, or formalin, CH_2O, into one molecule of sugar:

$$6CH_2O \longrightarrow C_6H_{12}O_6$$

Now the formula of formaldehyde suggests that it should be possible to make it from carbon dioxide and water, leaving one molecule of oxygen:

$$CO_2 + H_2O \longrightarrow CH_2O + O_2$$

If it could be proved that the green plant carries out these two reactions, the problem of photosynthesis would be solved. Unfortunately, the second reaction, though beautifully simple on paper, cannot be carried out in the laboratory except at extremely high temperatures and there is no evidence that it occurs in green plants. Formaldehyde is never found in green leaves, though of course it might be that the formaldehyde changes to sugar so rapidly that its presence cannot be detected.

Whatever may be the chemistry of the process, we can easily investigate the conditions under which it takes place. Let us first make sure that light is necessary.

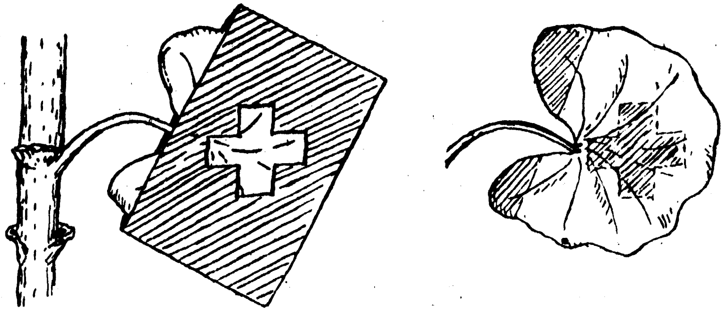


FIG. 49.—No starch formed in darkness.

> INQUIRY 54. Leave a geranium plant in the dark for a day. Then cover one of its leaves with a black paper envelope, having a design cut out of one side (Fig. 49). Put the plant in sunlight for a day; then remove the covered leaf and another. Dip them in boiling water to kill them, and wash out the chlorophyll by soaking in methylated spirits. When the leaves are colourless, lay them flat in a dish and cover them with dilute iodine solution. The leaf which was not covered with black paper will turn blue all over, while the other will be blue only where the light was able to reach it.

Notice that the test for photosynthesis is the presence of starch, not sugar. This is because the leaf might obtain sugar from some other part of the plant even in the dark, but it could not quickly change it into sugar.

The next inquiry is to verify that chlorophyll is necessary; that is, only green plants carry out the process.

> INQUIRY 55. Select a plant with variegated leaves (that is, with yellow or white blotches on its leaves), such as golden privet or laurel. Choose a leaf which has been in sunlight for a day, and draw a sketch showing the variegated pattern. Decolourize

and test for starch. It will be seen that the leaf turns blue only in those places where it was green at first.

The importance of carbon dioxide is shown as follows:

INQUIRY 56. Choose a plant with fairly long narrow leaves, such as a michælmas daisy. Enclose half a leaf in a small bottle containing caustic potash (Fig. 50). On testing, after a sunny day, the leaf will be found to have no starch in the part which, being inside the bottle, was deprived of carbon dioxide.

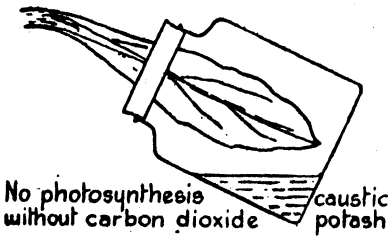


FIG. 50.

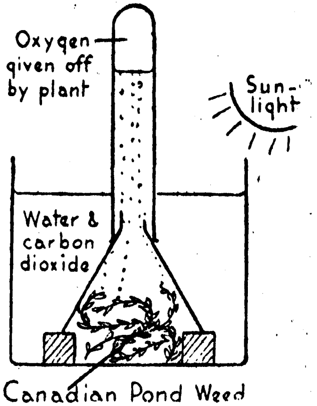


FIG. 51.—Green plants give off oxygen in sunlight.

It is difficult to show convincingly that plants give off oxygen during photosynthesis, but the following methods are often used:

INQUIRY 57. Cover a potted plant with a bell-jar and fill the jar with carbon dioxide. Expose to sunlight for some hours and test the gas in the jar with a lighted taper. If it stays alight, it proves that the plant has replaced some carbon dioxide by a combustible gas.

INQUIRY 58. Set up the apparatus of Fig. 51 and expose to sunlight for a full day. The gas which accumulates in the test-tube will be found to relight a glowing splint. This is a test for oxygen.

You will find it useful to discuss these two Inquiries in class, and find out why they are often unsatisfactory in their results.

We now have some evidence for believing what we have previously taken for granted about the process of carbon assimilation, namely:

It requires a living green plant, carbon dioxide and light.

By further inquiries it could be shown that other conditions are needed, such as a temperature at least slightly above freezing-point, and that the plant must also carry out other functions such as respiration and transpiration at the same time. It is not essential that the sun be shining brightly: indeed, the process will go on, at a reduced rate, even in artificial light.

Chloroplasts and Chlorophyll.

If a very thin leaf is examined through a microscope, it is seen that the chloroplasts, in which the green colouring-matter, chlorophyll, occurs, are little lens-shaped bodies scattered in the protoplasmic lining of the mesophyll (page 32). When a bright light shines on them they turn their edges towards it; but when the light is very dim they turn their flat sides so as to present the largest possible surface to the light.

Chlorophyll always contains at least two slightly different kinds of molecules, called Chlorophyll A and Chlorophyll B, and usually has other pigments (colouring-matters) mixed with it. The commonest of these is *carotin*, which gives the characteristic colour to the roots of carrots, and is largely responsible for the autumn colours of leaves.

As explained on page 92, chlorophyll contains magnesium, and cannot form unless this element, and iron as well, be present in the water absorbed by the plant. Another peculiar fact is that the plant cannot form chlorophyll in the dark, even when supplied with all the necessary chemicals. This explains why celery-stalks, which have been guarded from the light, are white, but if not "earthed-up" or otherwise protected from light, they turn green. The pale condition of plants in the dark is called *etiolation*.

Chlorophyll is easily extracted from plants by killing them and soaking them in methylated spirits; its chemical structure is fully understood, and it can even be made artificially; but it is of no use outside the living plant-cell. Although it enables the protoplasm of the plant-cell to carry out photosynthesis it will not carry out or even help in the process when separated from the cell. It cannot therefore be used in the laboratory to change carbon dioxide and water into sugar or starch. Chlorophyll is necessary for photosynthesis, but it is not the whole secret. The living protoplasm takes some fundamental, but so far unexplained, part in the process.

Plants and Light.

Our study of photosynthesis has shown that green plants cannot flourish without light, and that the organs which make use of the light are usually the leaves. It is therefore to be expected that the plant will have some means of ensuring that its leaves are placed in a suitable position to obtain all the light they need. We have already seen something of the way this is brought about (page 19), and we shall refer to it again in Chapter XVIII. At this point it is sufficient to notice that many plants which have large numbers of leaves often arrange them in a pattern which may at first seem haphazard, but on careful examination is found to allow every leaf to obtain unobstructed sunlight. This is especially the case with plants like the ivy, where, since the undersides of the leaves are completely hidden from the light, it is important for the upper surfaces to make the most of what light is available. The arrangement of leaves to prevent overlapping and allow each to face the sun, is called *leaf-mosaic*.

Food Storage in Plants.

Now that we have seen how plants obtain their food, we can go on to examine what happens to the food inside the plant before it is used up to provide energy or to make new tissue.

Most organisms, as explained on page 61, build up and maintain a food reserve inside their bodies. In plants, the logical place for these reserves is near, or below, the soil-level, where the plant does not have to hold up their weight, and they are unlikely to hamper the daily work of the plant, or attract the attention of hungry animals.

Consequently, it is found that, apart from fruits, by far the majority of food-storage organs in plants are subterranean (below ground). Indeed, this underground situation is so valuable that even when the storage organ is part of the shoot, it is still usually found below ground.

Perennation.

Since storage organs must, by their nature, be fairly safe from attack and able to withstand severe conditions, they are also suitable places for the development of buds, or other means of providing for the renewal of the shoot after the winter. Plants which have these storage organs are therefore usually able to come up in the same place for two or more years. This makes them biennials or perennials, and is called *perennation.*

Vegetative Propagation.

Food-storage organs, besides providing for perennation of the plant, may also provide for its reproduction, by developing from one storage organ several new shoots which may then become detached from the parent-plant and form new individuals. This method of reproduction without producing flowers is called *vegetative propagation.*

Food-storage, perennation and vegetative propagation are so closely related that we shall consider them all in the next few pages, although the three features are not always present in one type of plant.

Food-Storage in Roots. The *turnip, beetroot* and *carrot* are good examples of food-storage in *swollen tap-roots.* The carrot is a biennial, and the food stored up in the first year is used in the second to enable the shoot to grow rapidly and produce flowering branches.

The *Dahlia* and *Lesser Celandine* have fibrous roots. Some of these swell out with food and are called *root-tubers.* In the lesser celandine, which is a perennial, some tubers break off, each bringing with it a bud from the base of the stem and developing into a distinct plant.

Food-Storage in Stems. In some plants, a portion of the stem grows horizontally underground, becoming swollen with stored food and bearing terminal buds which give rise to aerial (above-ground) shoots. The rest of the underground stem is covered with scale-leaves, and has adventitious roots growing from its underside, while its underground growth is extended by lateral buds. Such a structure is called a *rhizome.*

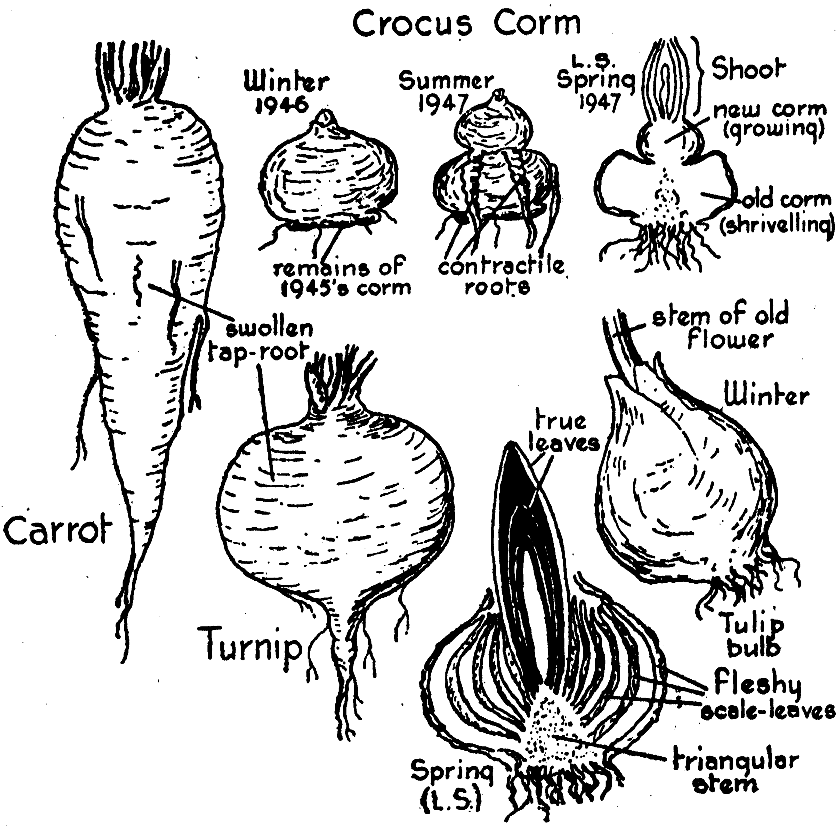


FIG. 52.—Food-storage in plants.

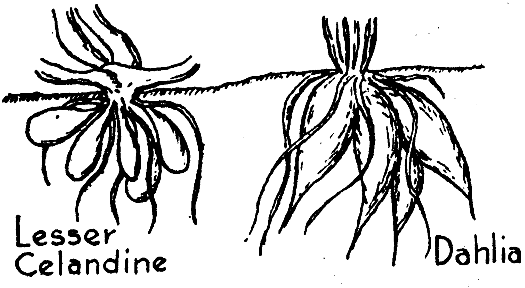


FIG. 53.—Root-tubers.

Examples of this are provided by the *Iris*, *Lily of the Valley*, and *Solomon's Seal*. In this plant, the "seal" is a large round scar left on the rhizome each year when the aerial shoot dies off. In time, the main stem of the rhizome withers away, leaving the branches separate and this is a means of vegetative propagation. In many plants, such as the *Nettle*, the rhizome is used for this purpose without storing much food. Grasses often use this method of colonizing ground, as anyone who has had to rid a lawn of couch-grass will know only too well.

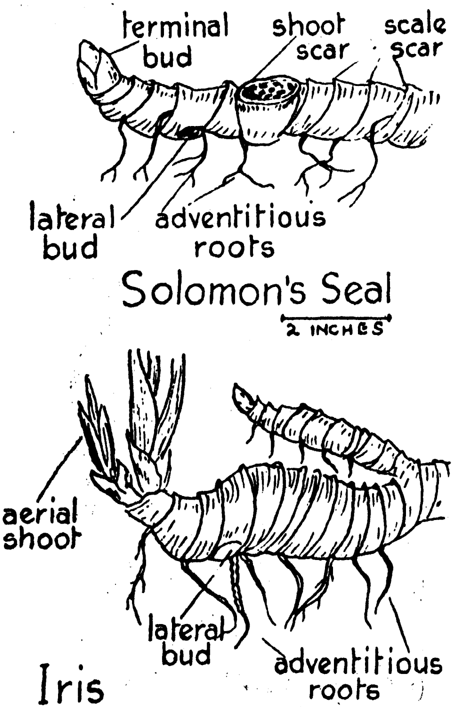


FIG. 54.—Rhizomes.

If the underground stem swells only at the tips of its branches, instead of along its whole length, the resulting structures are *stem-tubers*, as seen in the *perennial Sunflower* and the *Jerusalem Artichoke*. In the *Potato* (Fig. 55), the tubers become very much swollen. The "eyes" of the potato are scale-leaves, each with an axillary bud which can develop into a new plant.

Potatoes which are grown specially to provide new plants are called "seed potatoes", though of course they are not really seeds but vegetative reproductive structures.

Sometimes a tuber is formed by the base of the aerial shoot of the plant, as in the *Crocus*. This tuber is called a *corm*, and carries axillary buds which form the following year's shoot. Each year the corm is followed by a new one formed from the base of the new shoot, and the old corm dies away. This process would lift the base of the plant right above the soil-level in a few years, so this is prevented by the development of special *contractile roots* which, when they have taken a good grip on the soil, shorten rapidly and pull the plant back into the ground.

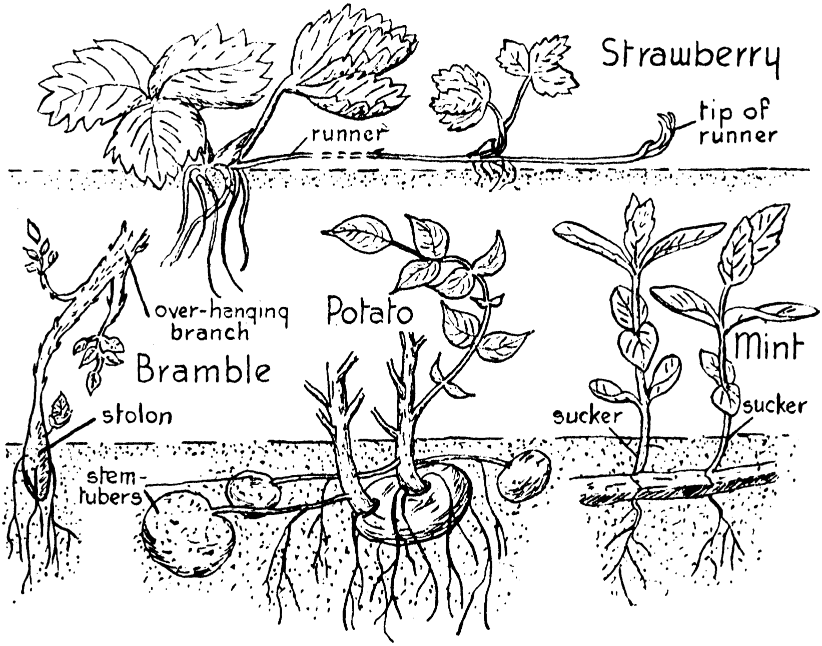


FIG. 55.—Vegetative propagation.

Food-Storage in Leaves. The *Tulip*, *Daffodil* and *Onion* are examples of plants which store food in the fleshy scale-leaves of a bud. This structure is called a *bulb*. In the axils of the true leaves of the bud are several axillary buds which, after the terminal bud has produced the aerial shoot, will develop into daughter-bulbs, which serve both for food-storage and perennation.

INQUIRY 59. Examine and draw examples of the structures described above, comparing them with Figs. 52 to 54.

Other Methods of Vegetative Propagation.

Occasionally reproduction is not obviously tied up with food-storage. We have seen examples of creeping plants in Chapter II. In some cases, the connection with the parent-plant gradually withers away, leaving the daughter-plants as separate individuals. The *Strawberry* produces slender, rapidly-growing branches which trail along the ground and turn up at the end, producing a new shoot which develops adventitious roots and so becomes a complete plant. During its early growth it draws nourishment along the *runner* which connects it to the parent-plant, but later it becomes independent of this connection, which withers away. In this way large patches of ground can be colonized by the plant, which thus forms *strawberry beds.*

A method of vegetative propagation, worth mentioning for its peculiar simplicity, is seen in the *Lily*, where the axillary buds occurring in the normal positions on the aerial shoot simply fall to the ground and grow into new plants. These detached buds are called *bulbils.*

Artificial Vegetative Propagation.

Since many of the plants which carry out vegetative propagation also have extensive food reserves they have naturally been developed as human food, and their natural reproduction is encouraged to provide crops.

In some cases it has been found that plants which do not normally reproduce in this way can be made to do so artificially, and where the plants are valuable providers of food it is often preferable to do this rather than rear them from seed, which in the case of trees may be a very slow process. It is also possible to combine the good qualities of two similar plants while eliminating the effects of their poorer features. Thus a plant which gives luscious fruit but is delicate may be combined with a hardy plant whose fruit is of poor quality.

This artificial propagation is carried out by *budding, grafting,* or *cuttings.* The nature of these operations should be clear from Fig. 56. They are successful only when very carefully carried out with suitable plants, which must be of very closely related strains.

The successful "striking" of cuttings has been made much easier by the discovery and extraction of growth hormones (page 153). By soaking the ends of cuttings in a solution of auxin they are induced to develop adventitious roots rapidly, and so are able to establish themselves quickly in their new environment.

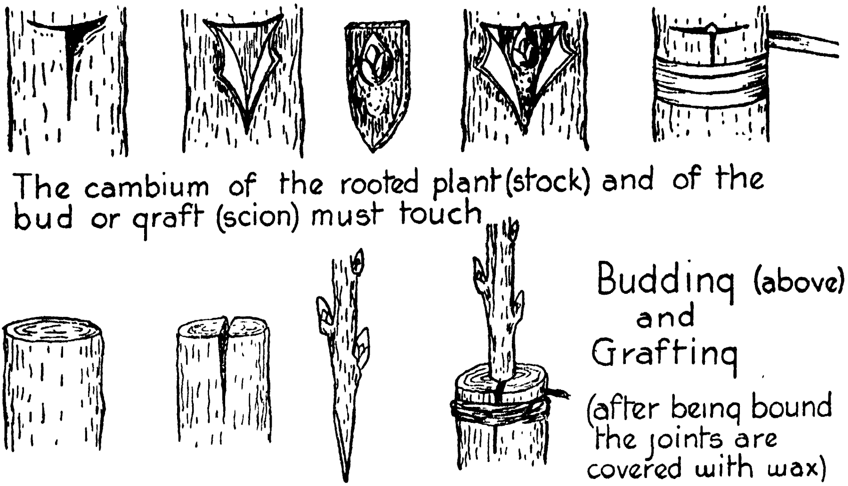

The cambium of the rooted plant (stock) and of the bud or graft (scion) must touch
Budding (above) and Grafting
(after being bound the joints are covered with wax)

FIG. 56.

Plants as Animal and Human Food.

This topic is far too vast to be treated in any but the barest outline, but is too important to be neglected. We are therefore compelled to restrict ourselves to a few examples.

All animals depend directly or indirectly on plants for their food. In nature, a very precise balance is set up between all the organisms in any area so that the plant and animal population is fairly constant. When Man takes a hand the balance is deliberately upset so as to increase the growth of those animals and plants which are useful to Man as food or in other ways: and to exterminate if possible those organisms which are harmful. Sometimes the attempt to control this balance produces unexpected results, as in Australia. Rabbits were introduced into

Australia by Man, and in a hundred years, because their natural enemies were absent, the rabbits had become a serious plague, eating thousands of tons of crops that were intended for sheep and humans. The problem became so serious that a rabbit-proof fence was built right across the continent, as far as from Land's End in Cornwall to John o' Groats in Northern Scotland.

The parts of plants most useful as food for animals and humans are the fruit and the underground storage-organs: so the plants used for food-crops are mainly those in which these two features are well-developed.

Among root-crops, turnips, mangolds, carrots and beet may be mentioned. Potatoes, onions and artichokes are often included, though, as explained above, the food-storage organs in these cases are part of the shoot.

It is impossible to give a comprehensive list of the fruit-crops, which range from cereals like wheat, barley, maize and rice, to large fruits like yams and coco-nuts; and from dry fruits such as nuts to succulent fruits such as plums and grapes. It is interesting to note that rice forms the staple food of more people than does wheat.

There are plants whose stems provide food, such as the sugar-cane, sago-palm, celery and rhubarb; others which are grown for their leaves, a few examples being cabbage (with its many relatives), watercress, kale and grass. Thousands of plants provide spices and drugs, and for these purposes any part of the plant, from the root-tip to the tip of the shoot, may prove to be valuable.

Apart from food, many plants are of great economic importance because they provide material for structural work or for textiles, dyes, varnishes and hundreds of other purposes.

Humus.

Even when a plant is left to die and rot in the ground it is still useful, because it is attacked by bacteria which release its proteins from the cells and redistribute the elements in the soil. The broken-down remains of plants enrich the soil and are called *humus*. Artificial soil can be made by mixing this humus with sand. By spreading rotting seaweed on the bare rocks, the people of the Aran islands, off the west coast of Ireland, made enough soil to grow their own food-crops.

Soil is considered in detail on page 164.

QUESTIONS

SECTION A.

1. Make notes on the part taken by each of the following in photosynthesis: sunlight; carbon dioxide; stoma; chloroplast.
2. Describe experiments to show that carbon dioxide is absorbed and oxygen given out in photosynthesis.
3. How could you show that light is necessary for photosynthesis? Explain carefully the purpose of each step in the inquiry.
4. Write equations which suggest how sugar may be formed in the leaves of green plants, from carbon dioxide and water. Why, do you think, is it so difficult to discover just what happens during the process?
5. Why are food-storage and vegetative propagation so closely connected? Describe three plants which possess storage organs and means of vegetative propagation, giving labelled diagrams.
6. Show the difference between the following: root-tuber and stem-tuber; corm and bulb; runner and stolon.
7. How would you show that a rhizome is not part of the root system? Why is it wrong to describe potatoes as (*a*) root-crops, (*b*) seed potatoes?
8. Name in each case two examples of plants which provide human food from (*a*) the root, (*b*) the stem, (*c*) the leaf. What type of plant provides the majority of the food for animals which are eaten by Man?

SECTION B.

1. Describe how the photosynthetic work of a leaf would be affected by covering (*a*) the upper surface, (*b*) the lower surface, with vaseline. Explain the effect of the vaseline.
2. Which colours of light would you expect to be most effective in promoting photosynthesis? If a light of exactly the same colour as chlorophyll were substituted for sunlight, would photosynthesis increase or decrease? Explain your answer.

CHAPTER VIII

MAMMALS

Of all animals, the most highly developed are the mammals. Human beings are mammals, and so are livestock and most domestic animals, with the exception of fowls. Indeed, most people connect the word "animal" so closely with mammals that they are surprised to learn that birds, reptiles, fish, insects, etc., are also animals.

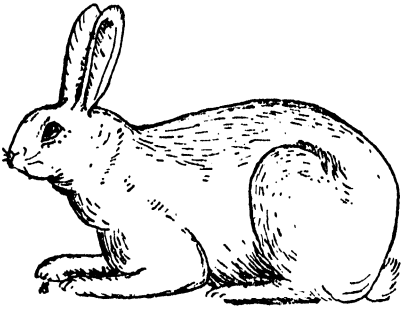


Fig. 57.—A rabbit.

We shall begin our study of animals with a mammal: and as an example we take the rabbit, because rabbits are small, easy to rear and handle, and can be bought and fed cheaply. Since, however, there is great variety in the structure and habits of mammals, we must remember that there is really no such thing as a "typical" mammal; so we shall frequently consider, when describing a particular feature of the rabbit, how that feature may differ in other mammals.

External Features.

As regards size, the rabbit comes rather low in the list of mammals (Plate I). The biggest mammal is the whale, which may reach a length of a hundred feet and weigh up to three hundred tons. The harvest mouse is one of the smallest mammals, and weighs only three or four ounces. The wild rabbit is fairly lean, about eighteen inches long when stretched out, and weighs between five and ten pounds. Some tame rabbits, such as the Flemish Giant, may weigh nearly twenty pounds.

The body is covered with hair which, being close-set and smooth, is called fur. The presence of hair is one of the means of distinguishing mammals from other vertebrates, though a few mammals, especially those which live in the sea, lose nearly all the hair from their bodies as they grow.

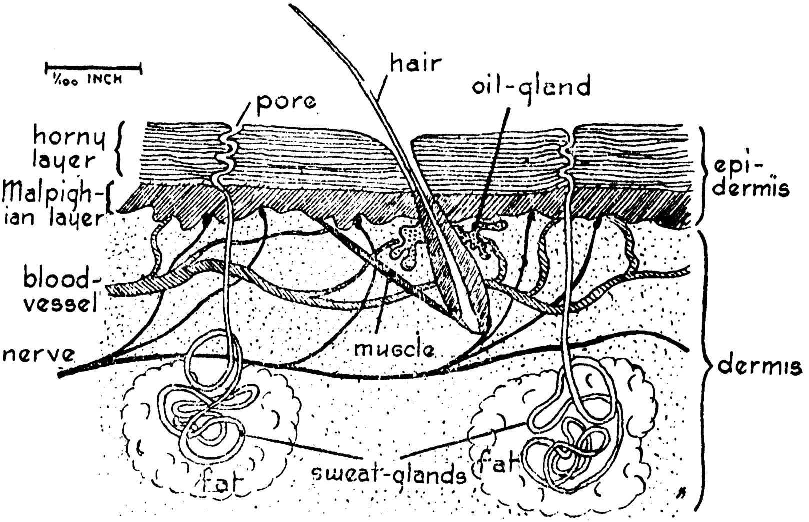


FIG. 58.—Transverse section of human skin.

Skin and Hair.

The skin is in two layers: the *epidermis* (Greek: outer skin) or cuticle, and the *dermis*, or true skin. The epidermis has no blood-vessels, and its surface-cells are constantly peeling off and being replaced. Besides the dead horny outer cells, it contains the openings (*pores*) of sweat-glands which are situated in the deeper layer, and it produces hairs. Some of its cells contain *pigment* (colouring). These pigment-cells form the *Malpighian layer* of the epidermis, and act rather like the cambium in a plant, giving rise to all the other cells of the epidermis. (*Malpighi* is the name of a famous papal physician who lived in the seventeenth century.)

A hair is produced by part of the Malpighian layer sinking into the dermis and forming a little sac called a *hair-follicle.* The hair, a hollow column of cells which contain a substance called *keratin*, making them horny, grows from the base of this follicle. If the follicle is round in cross-section, the hair will be straight; if oval, the hair is curly; and if flat, the hair is wavy. The hair always emerges from the skin in a slanting position.

Each hair has a nerve, blood-vessel, muscle-fibre and an oil-gland (*sebaceous gland*) which lubricates it. Just pause for a moment and reflect on this. Imagine yourself, for instance, trying to provide every hair on a fur coat with a miniature telephone wire, water-pipe, piece of elastic and oil-can, and connecting them all up so that they would work without further attention.

Finger- and toe-nails are formed by groups of epidermal cells, and consist of plates of tightly-packed, dead, horny cells.

Teeth are developed from the epidermis, very early in life, and lie hidden in the gums for some time before breaking through.

The dermis is thicker than the epidermis, and has a complicated structure containing in its ground-tissue (*connective tissue*) blood-vessels, coiled sweat-glands, nerves, and adipose tissue ("fat").

In general, the skin protects the body, helps to rid the body of waste substances, controls the temperature, carries sense-organs, and produces special structures—hair, nails, teeth.

General Appearance.

The general shape of the rabbit is seen in Fig. 50. Like most vertebrates it has a *head* and *trunk*, joined by a *neck*, two pairs of *limbs*, and a *tail*, which is an extension of its backbone.

The body of the rabbit, as of most animals, can be divided into two similar halves, by a line passing from nose to tail, called a *median* line. Such an animal is *bilaterally symmetrical* (Latin: two sides alike). It has a front (anterior) and a hind (posterior) end, a back (dorsal) and a belly (ventral) surface, and right and left sides (lateral surfaces). Some of these terms will be found useful when we describe less familiar animals.

The eyes and ears are prominent: the upper lip is split by a central *cleft*, and bears long sensitive hairs ("whiskers"). The fore-limbs (front legs) are rather short, and the hind limbs long and powerful, enabling it to leap great distances. We shall compare these features with those of other mammals when we examine them in detail. The tail is short, and curves up close against the body. The fore-legs have five toes, the hind-legs only four.

Life-History.

The rabbit lives underground, in burrows, which it digs with its legs. The female rabbit has about four families of young each year, with about half a dozen in each. The rabbit population would increase alarmingly if the animals did not have so many enemies.

> INQUIRY 60. Suppose a pair of rabbits become adult at six months, and have four litters, with six young in each, every year afterwards. How many rabbits would this produce in two years, if the offspring reproduce at the same rate as the parents?

It is very amusing to lie hidden and watch the antics of rabbits. They are *gregarious* (that is, they live in communities) and feed on grass and any other tender crops they can find. Their eyes are set so far to the sides of their heads that they can see behind them, and the first rabbit to spot a suspicious movement thumps on the ground with its hind-legs. All the rabbits nearby then scurry for shelter, their white stumpy tails flashing an alarm-signal to all those behind them.

Because they eat only plants, rabbits are described as herbivorous (page 57).

The young, as in the case of most mammals, remain in the mother's body until they have developed into recognizable reproductions of their parents. After birth, they are fed for some time with milk from special glands in the skin of the mother's body, which form the milk from the mother's food.

These glands are called *mammary glands*, and from this word the name "mammal" is derived. This method of feeding is called *suckling*, because the offspring draws the milk into its mouth by suction.

Rabbits are hunted by Man, and by stoats, weasels and dogs.

Millions of tinned rabbits and rabbit-skins are exported from Australia every year.

Being easily tamed, the rabbit is a favourite domestic pet, and many varieties have been developed by careful breeding; some of these have very valuable skins.

Skeleton.

The skeleton of a mammal is mainly *bone*, a very strong tissue consisting of cells greatly strengthened by deposits of calcium phosphate. Bone develops from *cartilage*, which is tough, but much softer. As the animal grows older, most of its cartilage is transformed into bone, though in some parts of the body, notably at the ends of the long limb-bones, a pad of cartilage persists throughout life. It is well known that a baby's cranium (the top of its head) consists of four separate pieces of cartilage, with a space between them. The skin above this space can be seen rising and falling in time with the beating of the child's heart. By the time the baby is a year old, the space has closed up and the four cartilages have formed a single dome of bone.

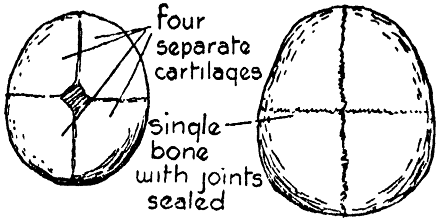


FIG. 59.—Baby's cranium at birth, and after one year.

A permanent fusion between bones is called a *fixed joint*.

The "foundation" of the skeleton is the *backbone* or vertebral column, to which are attached the *skull*, the *ribs*, and the *limb-girdles*. (Plate I). The purpose of the skeleton is to maintain the shape of the body, support the organs, and provide a rigid structure against which the muscles can pull. Inside the long bones of the limbs, important parts of the blood, called corpuscles (page 144), are formed.

Vertebral Column.

The backbone consists of a series of hollow rings, placed end-to-end, forming a tube which encloses and protects the

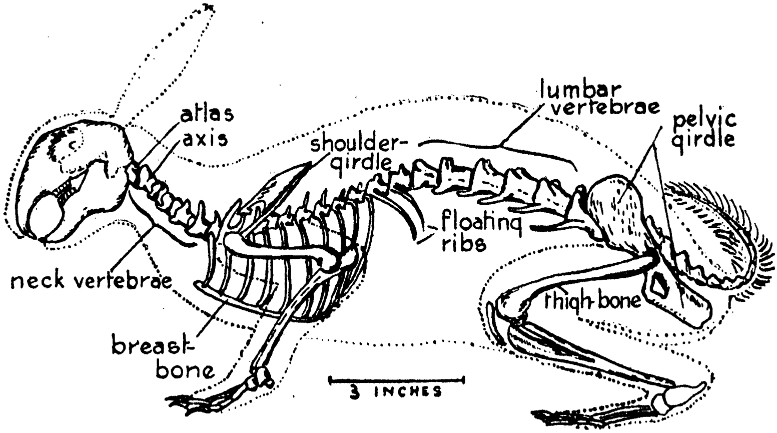


FIG. 60.—Skeleton of a Rabbit.

spinal cord. This is a bundle of nerves connecting the brain with the other parts of the body.

Each ring is called a *vertebra*, and they form five groups, as follows:

The *neck-vertebræ* (cervical): there are seven of these, even in animals like the giraffe, with its long neck, and the mole, with hardly any. The first two vertebræ, called the atlas and the axis, support the skull, and allow it to rotate and to nod.

The *chest-vertebræ* (thoracic): each of these twelve vertebræ bears a pair of ribs which curve round to the front of the body, forming a bony cage which protects the heart and lungs within. Most of the ribs are attached in front to a dagger-shaped bone, the *breast-bone* or sternum. The lower pairs (the last two pairs in Man, the last

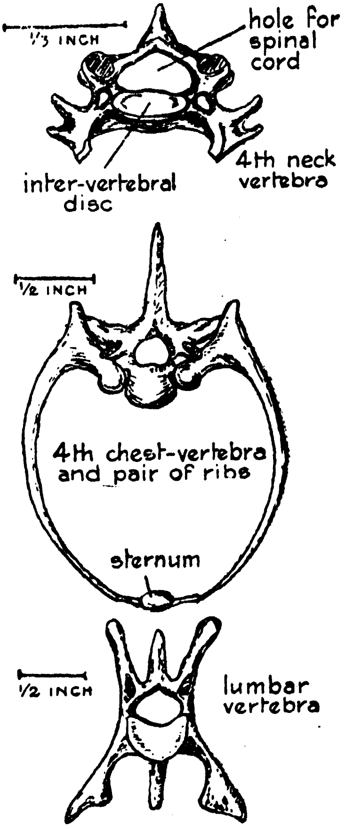


FIG. 61.—Vertebræ of a Rabbit.

four in the rabbit) are attached only to the backbone, and are free in front (*floating ribs*).

The *loin-vertebræ* (lumbar): these bones (five in Man, seven in the rabbit), are the biggest vertebræ in the body. They have spiny projections or *processes* to improve their support of the tissues of the back.

The *sacral vertebræ*: these four or five vertebræ are fused together and support the *pelvis*, which is a basin-shaped bone supporting the intestine and other organs, and providing sockets for the attachment of the hind-limbs.

The *tail-vertebræ* (caudal): there are about sixteen of these in the rabbit, and they are progressively smaller and simpler towards the end. In Man, there are only about four, and they are fused together into a short structure called the *coccyx*, which does not project from the body.

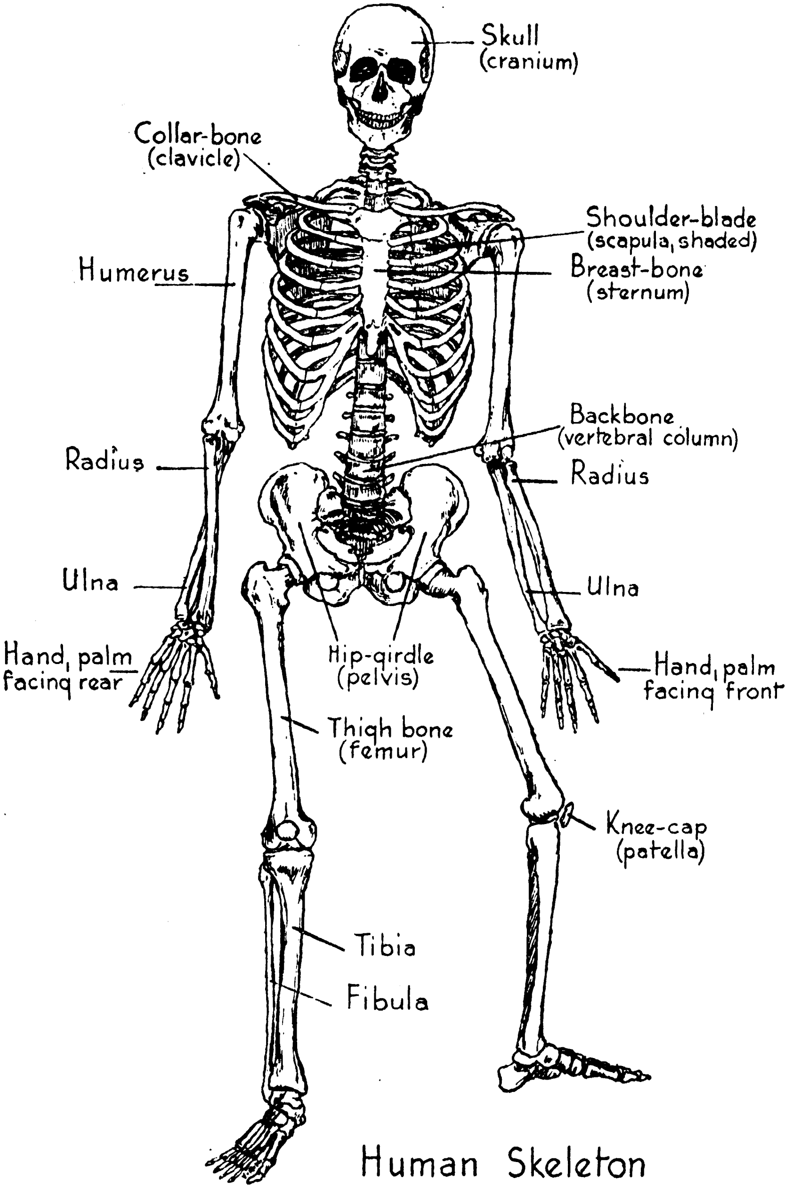
All the vertebræ except the sacral and, in Man, the coccyx, have "washers" of cartilage between them, called *intervertebral discs*, which act as shock-absorbers and allow the spine to bend slightly.

The Skull.

The skull is a mass of fused bones, protecting the brain and the main sense-organs, the eyes, ears, nose and tongue. The lower jaw is *hinged* to the skull. The teeth, though formed from skin, are firmly anchored in the jaws.

Teeth.

A tooth consists of an outer layer of extremely hard *enamel*, with a layer of softer material, *dentine*, beneath, enclosing a central *pulp*, which is supplied through the base with blood-vessels and nerves. In most mammals this opening at the base gradually closes, and the tooth stops growing; but in the rabbit it remains open and the teeth go on growing throughout the animal's life. As a result, unless it were able continually to wear them away by gnawing and grinding its food they would, in time, wedge its mouth permanently open and kill it. This is the case with all gnawing animals (rodents), such as rats and mice.



Human Skeleton

FIG. 62.

Teeth are of various shapes and sizes according to the work they have to do. A mammal's front teeth are called *incisors* (Latin: cutters). Beyond these there is usually in each jaw a

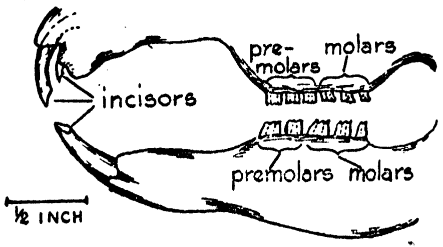


FIG. 63.—Teeth of Rabbit.

pair of sharp teeth for killing and holding its prey. These are the *canines* (Latin: *canis*, dog). Herbivorous animals like the rabbit do not need these teeth and they are accordingly missing, leaving a big gap between the incisors at the front and the grinding-teeth at the back of the mouth.

The grinding-teeth of mammals are of two kinds: *molars* at the back of the jaws, and premolars between them and the canines.

Milk-Teeth. Nearly all mammals have two sets of teeth in the course of their lives. The first set, or milk-teeth, are pushed out by the permanent teeth growing from the same sockets. The molars are not represented in the set of milk-teeth, but the pre-molars, and all the other teeth, are *pre*ceded by corresponding milk-teeth.

Dental Formula. To simplify the description of a mammal's teeth their arrangement is usually expressed by a *dental formula.* Since the right and left sides of the mouth are alike only one side is considered. The number of incisors, canines, premolars and molars is stated, in that order, by four fractions, in each of which the numerator refers to the upper jaw, and the denominator to the lower. The dental formula of the *rabbit* is $\frac{2\ \ 0\ \ 3\ \ 3}{1\ \ 0\ \ 2\ \ 3}$, making a total, for both jaws, of twenty-eight teeth.

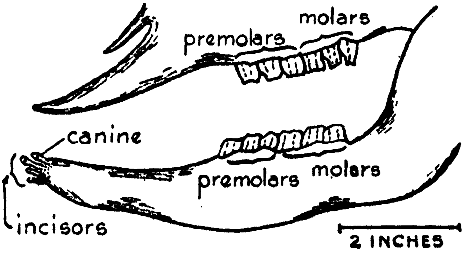


FIG. 64.—Teeth of Sheep.

The *sheep*, which, though herbivorous, does not gnaw its food, has no incisors or canines in its upper jaw. In their place it has a horny plate against which it can press the grass and cut it with the incisors and small canines in its lower jaw. The grinding-surfaces of the premolars and molars have ridges running from back to front, and the sheep grinds its food by moving

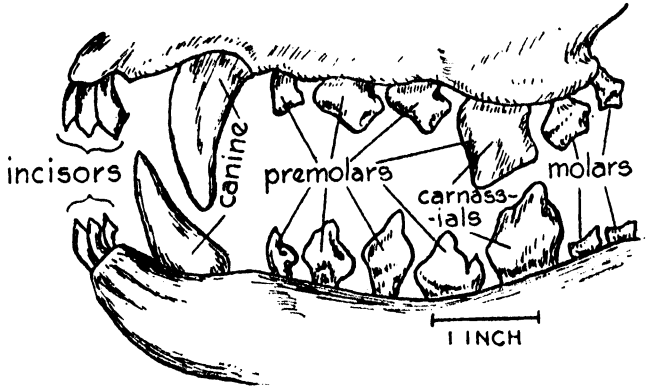


FIG. 65.—Teeth of Dog.

its lower jaw from side to side. Its dental formula is $\frac{0\ 0\ 3\ 3}{3\ 1\ 3\ 3}$, and it has thirty-two teeth.

The teeth of the *dog* are well adapted for dealing with its carnivorous diet. It has sharp incisors for cutting the meat from bones, powerful canines for piercing and holding its prey, and strong well-shaped premolars and molars. In each jaw is an extra-large tooth on each side, called the *carnassial* (flesh-tearing). Its dental formula is $\frac{3\ 1\ 4\ 2}{3\ 1\ 4\ 3}$, total forty-two.

Human teeth are "general-purpose" teeth, and can deal with both plant and animal material. The four molars at the back of the mouth develop several years after the others (usually between the ages of twenty-one and twenty-five). They are too far back to be of much use, and often decay after a short time. The dental formula in Man is $\frac{2\ 1\ 2\ 3}{2\ 1\ 2\ 3}$, making a total of thirty-two teeth.

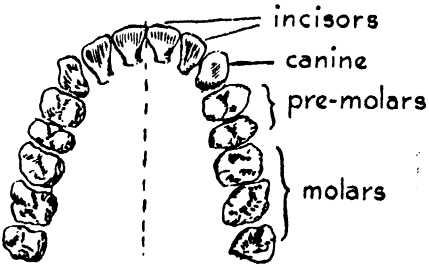


FIG. 66.—Human teeth.

Limb-Girdles.

The *pelvic* girdle has been described already. It is a massive structure in all mammals. The *pectoral* girdle (Latin: *pectus*, chest) consists of the *shoulder-blades* (Latin: *scapula*, shoulder-blade), which protect the dorsal side of the chest and provide sockets for the shoulder-bone of each arm, the *humerus* ("funny-bone"). In many mammals there is also a straight finger-like bone at the front of the chest—the *collar-bone* or *clavicle* (Fig. 54). In the rabbit this is poorly developed, and in the cat family (tigers, etc.), is absent, as it would easily break when the animal alighted on its front legs after leaping from a height.

The names of some of these bones may be remembered from their religious associations, e.g., pectoral cross, scapular, humeral veil.

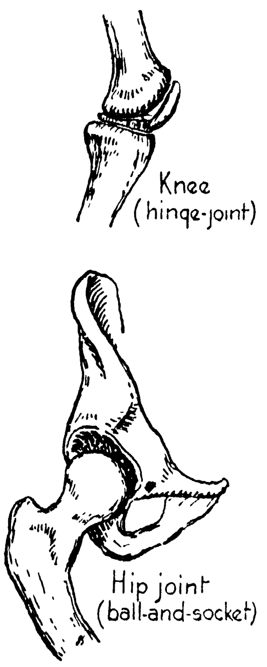


FIG. 67.—Human joints.

Limbs and Joints.

The limbs of all mammals are constructed to the same fundamental plan, but with many variations according to the functions they have to perform. The part of the limb attached to the girdle always has a long, strong bone, called the *humerus* (upper-arm bone) in the fore-limb, and the *femur* (thigh-bone) in the hind-limb. These bones are joined to their girdles by *ball-and-socket joints* (Fig. 67) which allow movement in several directions. At the opposite end to this joint, each bone forms part of a *hinge-joint* (knee or elbow), beyond which are the remaining long bones of the limb.

In the fore-limb these are called the *radius* and *ulna*, and in the hind-limb, the *tibia* and *fibula*. In all mammals the tibia and fibula are fastened tightly together and act as one bone: and in the rabbit this applies also to the radius and ulna. In many mammals, however, including Man, the radius can rotate round the ulna, allowing the outer end (extremity) of the limb to be turned through 180° or more (i.e. either palm-forwards or palm-backwards, Fig. 62).

The extremities of the limbs are the parts showing greatest variety of structure, though they are all based on a plan which is seen in a simple form in the human hand, and is known as the *pentadactyle* limb (Greek: five-fingered). The wrist and "hand" of the rabbit's fore-limb are very like those of a man in skeleton, but the foot of the hind-limb has only four toes. The foot of a human being differs from that of most mammals because a man normally walks with the whole weight of his body on the hind-limbs.

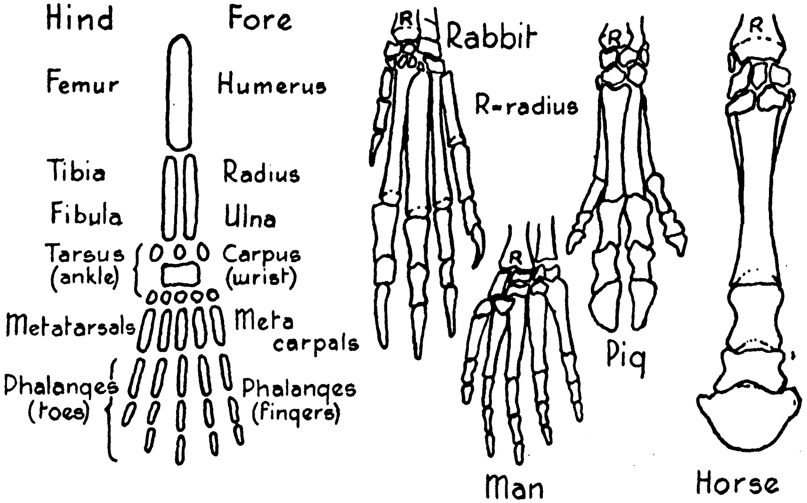


FIG. 68.—Plan of pentadactyl limb, with examples of fore-limbs.

It should be noted that, in the hind-limbs of many mammals, the prominent bend ("dog's leg") in the limb is not the knee-joint but the ankle-joint, which folds the opposite way to the knee, as it does also in Man. The knees of these animals are high up in the legs (Fig. 69).

Muscular Movement.

A vertebrate moves its body and limbs by the action of muscles on various parts of its skeleton. The muscles concerned are

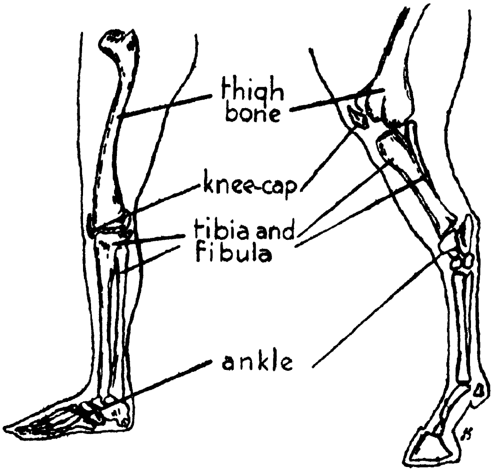


FIG. 69.—Comparing human leg with hind-leg of horse.

mainly *voluntary* muscles: that is, their movement is controlled by conscious nerve-messages from the brain. These muscles are also called *striped muscles*, because of the appearance of their fibres under the microscope.

Muscles work by contraction — they can pull, but cannot push. Any pushing movement by the animal is brought about by the pulling action of muscles, converted into a push by part of the skeleton acting as a lever.

The contraction of muscles is easily observed by raising the forearm. This is brought about by the *biceps* muscle (Latin: two-headed) on the front of the upper arm becoming shorter and thicker. This muscle is attached by *two tendons* or sinews at the top of the humerus, to the clavicle, and its lower end is inserted in the ulna, just in front of the elbow (Fig. 70).

When the biceps muscle is relaxed, the forearm is lowered, partly by its own weight, but partly also by the pulling-action (contraction) of a muscle behind the upper arm, called the *triceps*. This is attached to the shoulder-blade and the top of the humerus by *three* tendons, and its other end is attached to the ulna

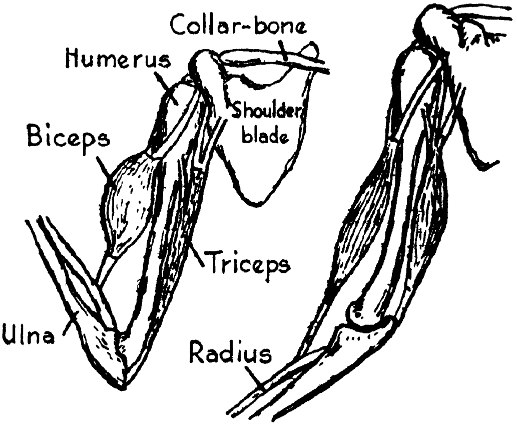


FIG. 70.—Human arm, bent and extended.

just behind the elbow. Without the triceps muscle it would not be possible to straighten the arm when holding it above the head.

Pairs of muscles which work against each other like the biceps and triceps are called *antagonistic pairs*, and the movements of all the limbs, fingers and toes, are produced in this way. The body is maintained in its normal position only by the continuous action of these pairs of muscles all over the body. Thus a person in a faint is *limp*, and is unable to support himself erect, because both muscles of each pair are relaxed.

When, on the other hand, both muscles contract violently at the same time, the limb becomes rigid, causing a painful condition called *cramp*.

The gentler, normal pulling of these pairs of muscles is called *muscular tone*. When we are very tired or depressed, the muscles relax and allow the body to droop. Physical exercise aims at raising this muscular tone and keeping the body in a state of muscular balance (poise).

Involuntary Muscles.

There are many muscles in the body which are not attached to bones. It has been seen already that every hair has its own muscle; the passage of food through the body is caused by muscles, as is the circulation of the blood, and many other operations which go on without our being aware of them. Muscles producing these effects are mainly automatic or involuntary muscles. They are all, except the heart, fully controlled by the brain, but we are not normally conscious of the control. The tissue of these muscles is *unstriped*, when seen through a microscope. The heart-muscle is completely automatic, and can go on contracting even after removal from the body. It is a special type of muscle called *cardiac* muscle.

Modified Limb-Skeletons.

Many mammals have modified limbs, some of which will be described in later chapters. Here we have space to mention only a few, where the modification is not only in external appearance but in the skeleton as well.

Hoofed animals (Ungulates). These include the horse, ass, zebra and other animals in which each hoof is formed from a single toe, the third. These animals therefore support the whole weight of the body on four toe-nails.

Cloven-hoofed animals. These are ungulates (Latin: nail) in which each hoof is formed from two toes, the third and the fourth. They include the camel, sheep, ox, pig, and many others.

Bats. These mammals have hands which are modified into a framework for their wings, which consist of skin stretched between their long fingers and the sides of the body and continuing between the hind-limbs and tail.

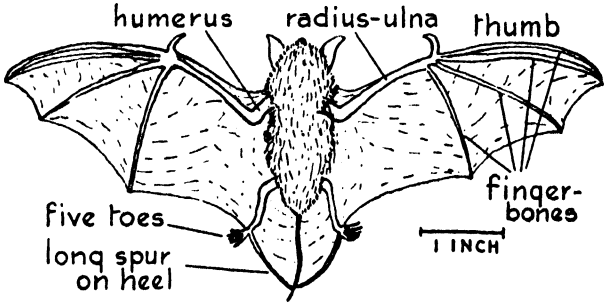


FIG. 71.—The Bat, a mammal with modified limbs.

QUESTIONS

SECTION A.

1. Describe the external appearance of two well-known mammals, showing in each case how appearance is related to the animal's habits of life.
2. What are the main purposes of a bony skeleton? Name parts of the skeleton chiefly concerned, in each case, in the rabbit.
3. Write a short essay on the different types of dentition (teeth-arrangement) in mammals.
4. Name the three main types of joint in a bony skeleton, and name two examples, from different parts of the rabbit's skeleton, of each type.
5. Give a labelled diagram of a mammalian limb-skeleton. Explain how the muscles bend and straighten the limb.
6. Draw a lumbar vertebra of a rabbit, and describe how other vertebræ differ from it in shape.
7. Why cannot the human foot be taken as a typical mammalian foot? Describe the muscular operations concerned in the action of standing on tiptoe.
8. Write notes on the skull, pectoral and pelvic girdles of the rabbit.

CHAPTER IX

DIGESTIVE SYSTEMS OF MAMMALS

THE internal organs of all vertebrates are grouped into fairly distinct systems, according to their functions, as, for example, the *skeletal*, *digestive*, *respiratory*, *nervous*, and *urinogenital* systems. We have already considered the skeletal system, and the muscular system. We begin this chapter by seeing something of the layout of the other internal systems; then we shall examine the digestive system in more detail, leaving the remaining systems for later chapters.

Layout of Internal Organs.

You will be shown the internal appearance of the rabbit, probably as a demonstration dissection, or by preserved specimens.

Beneath the skin of a vertebrate's trunk is the *body-wall*, made up of sheets of muscle and connective tissue. Inside this wall is the body-cavity, containing the *viscera*, or internal systems named above. In mammals, this cavity is divided by a sheet of muscle (the *diaphragm*) into upper and lower portions, called respectively the *chest* (thorax) and *belly* (abdomen).

Chest Cavity.

The main organs in the chest are the *lungs* and *heart*, protected by the cage formed by the ribs, sternum and pectoral girdle. When the animal is alive, the two lungs almost fill the thorax, but when it is opened they collapse and seem quite small. A strong tube, stiffened by rings of cartilege, and called the *trachea* (windpipe), leads from the throat into the thorax, and divides into two branches (*bronchi*), one leading to each lung. Lying on the ventral side of the trachea are two glands (p. 132): a small one, the *thyroid*, near the top, and a large *thymus* partly covering the heart, which is centrally placed between the lungs. (The heart-beat is stronger on the left side, so many people think the heart itself is on the left.)

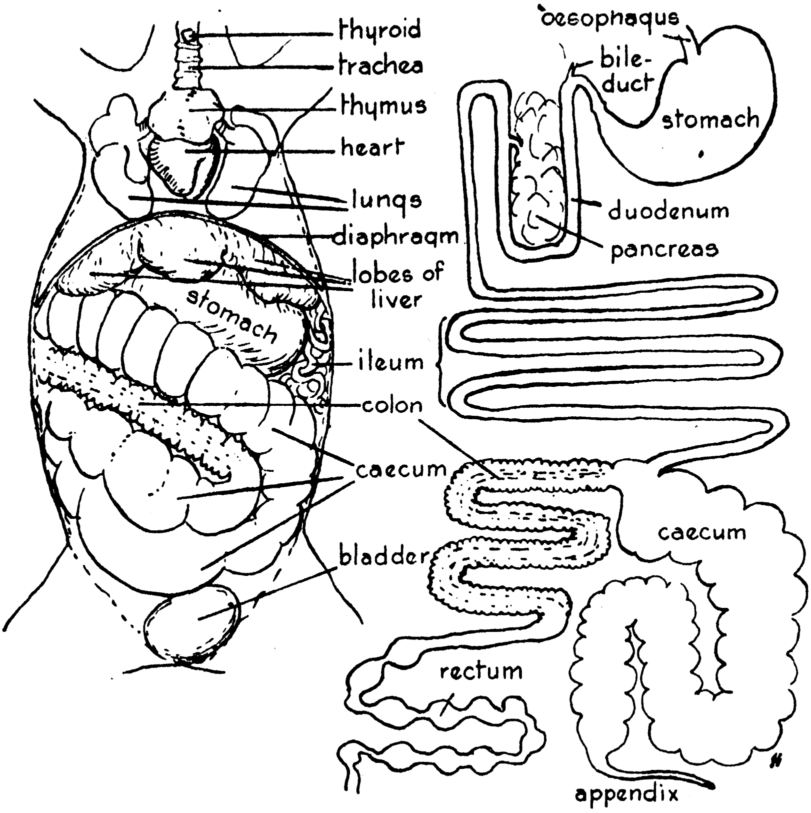


FIG. 72.—Internal organs of Rabbit, shown in place, and unravelled for examination.

Each lung is encased by a double sac, the *pleura*, with fluid between its walls to lubricate them when the lung expands and contracts.

The heart is also encased in a double sac, the *pericardium*. (Latin: round-the-heart.)

Running right through the thorax from the mouth to the abdominal cavity is the tube through which food is swallowed.

It lies behind the trachea and is called the *œsophagus* (Greek: food-carrier) or gullet.

Several large blood-vessels can also be seen, associated with the heart. They will be described when dealing with the respiratory and circulatory systems.

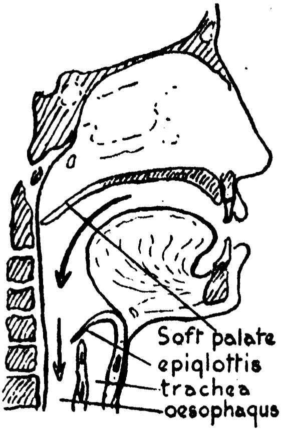


FIG. 73.—Section of human face, showing path of food being swallowed.

Abdominal Cavity.

The *liver*, a large much-lobed organ, lies snugly against the underside of the diaphragm, partly hiding the *stomach*. Embedded in the liver is a dark-green sac, the *gall-bladder*, from which a tube, the *bile-duct*, leads past the stomach, and enters the intestine just beyond it.

The œsophagus goes through the diaphragm from the thorax, and leads to the stomach, which is a pear-shaped bag with strong muscular walls. It is wide at the beginning, the narrower end leading to the *intestine*.

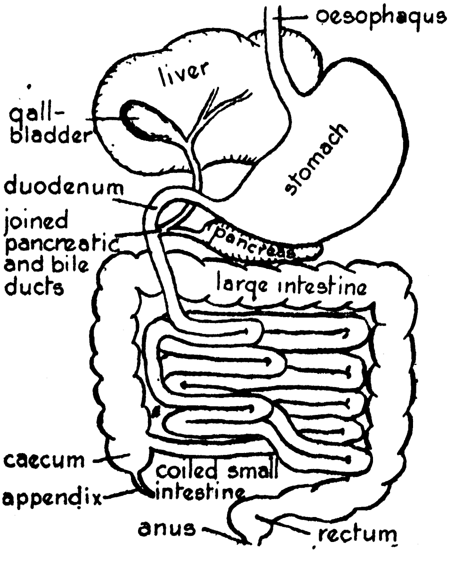


FIG. 74.—Human digestive system.

The first part of the intestine is bent into a U-shape, and is called the duodenum (Latin: twelve, because, in Man, it is roughly twelve inches long). Between the arms of this loop is the *pancreas* or sweetbread, a very loose, branched gland, with a tube, the pancreatic duct, leading into the duodenum. The *bile-duct*, from the liver, also enters the duodenum. (In Man, these two ducts join together before entering the duodenum.)

The next part of the intestine is a narrow tube, about eight feet long in the rabbit, called the *ileum*. The ileum and the duodenum together are called the *small intestine* (because of its diameter, not its length).

The rest of the alimentary canal (food-channel) is the *large intestine* consisting of a wide tube, the *colon* (about eighteen inches long in the rabbit) and a narrower tube, the *rectum* (thirty inches) leading to the *anus*, the opening by which solid waste matter leaves the body.

At the point where the small and large intestines join there is a side-connection, the *cæcum*, which in the rabbit is relatively very large, about twenty inches long, and much wider than any other part of the intestine. In Man, the cæcum is very small. The cæcum ends in a narrow pencil-like tube, the appendix.

Because of its great length, about twelve feet in the rabbit, twenty-seven feet in Man, the intestine has to be coiled up to fit in the abdominal cavity. It is slung from the dorsal surface of the body-wall by thin sheets of tissue, called mesenteries, which hold its coils together, and have to be cut in order to lay it out for examination.

Attached to the body-wall are two red oval bodies, the *kidneys*, from each of which a narrow tube, the *ureter*, leads to the *bladder*, a thin-walled sac which stores urine, and periodically discharges it from the body.

There are also reproductive organs, but these differ so widely in the two sexes that it will be more convenient to describe their appearance when dealing with the function of reproduction.

Digestive Processes.

When food enters the mouth, it is ground up and mixed with *saliva*, a watery liquid produced by a number of *salivary glands*, four pairs in the rabbit, three pairs in Man, which are embedded in the tissues of the mouth. With the aid of the *tongue*, which is muscular, and covered with sensitive spots (taste-buds), the food is rolled into a pulpy ball. The tongue manipulates the food by pressing against the roof of the mouth;

the front part of this is hard and ridged (the *hard palate*), while the back is soft and flexible (soft palate). The food is then passed into the *pharynx*, which is the opening of the œsophagus. While food is being swallowed, the soft palate rises and blocks the entrance to the back of the nose. At the same time, the opening to the windpipe is blocked by a small flap of muscle, the *epiglottis*. Sometimes this does not fall into place quickly enough, and food goes down the wrong way. It is then driven out again by coughing.

In the gullet, the food is forced down by waves of muscular contraction into the stomach. During this time, some of the starch in the food is being changed into sugar by a chemical in the saliva, called *ptyalin*.

> INQUIRY 61. Chew a few grains of wheat, and note how they slowly begin to taste sweet as the saliva changes the starch to sugar in the mouth.

The saliva in the mouth acts on food particles left on the teeth, turning starch to sugar solution which flows away, instead of remaining as food for the many bacteria which are always in the mouth.

Enzymes.

Ptyalin is an example of a class of chemicals found in organisms, and able to cause or speed-up chemical actions which would not occur, or only very slowly, without their help. These chemicals are called *enzymes* (Greek: "in yeast", because that is where they were first detected). They may be described as organic catalysts. They are very powerful, but only in certain conditions. Ptyalin, for example, will only act on starch, and is useless if acid is present. For this reason the saliva is alkaline.

On reaching the stomach, the food is churned round and mixed with *gastric juice*, which pours out from glands in the stomach-wall. This juice contains three important chemicals: *hydrochloric acid*, and two enzymes, *rennin* and *pepsin*. The acid kills germs, stops the action of saliva, and enables the pepsin to begin digesting the proteins. The rennin acts on milk (and so is more plentiful in young animals), turning it into semi-solid curds and thus keeping it in the stomach until the pepsin has had time to act on it. The *rennet* which is used for making junket is extracted from calves' stomachs.

Digestion in Small Intestine.

Both ends of the stomach are closed by muscular rings called sphincters (Greek: fasteners), which act rather like purse-strings. The one at the entrance is called the *cardiac* sphincter, because it is "near" the heart; the one at the exit is called the *pyloric* sphincter (Greek: *pylorus*, gate). It will open only when the stomach contents are no longer acid: that is, when the gastric juice has finished its work. Then the food passes on into the small intestine, where the serious business of digestion and assimilation really begins.

The arrival of the food in the intestine is the signal for the pancreas to send *pancreatic juice* into the duodenum. It will be remembered that the pancreas is near, but not in, the duodenum, and a chemical message has to be sent from the duodenum, through the blood, to the pancreas, when its juice is required. Substances which act as messengers in this way are called hormones (Greek: exciters).

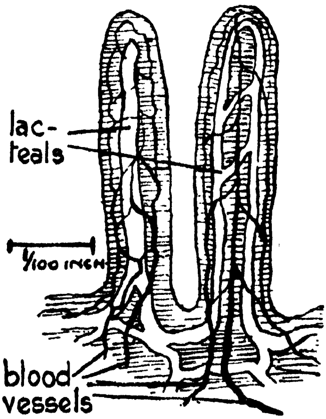


FIG. 75.—Villi on the inner surface, small intestine.

Pancreatic juice contains three enzymes, *diastase*, *lipase* and *trypsin*, which act on carbohydrates, fats and proteins respectively. *Bile* from the gall-bladder is mixed with the food at this stage, and helps to break up the fat into small globules so that the lipase can act on it.

As the food is forced along the small intestine it comes into contact with several other juices secreted by the intestine-walls, and is at last ready for absorption.

Absorption of Food.

The inner surface of the small intestine is greatly increased by folds and by projections called *villi* (Latin: *villus*, hair), and the wall is very richly supplied with blood-vessels, running close to the inner surface. Consequently, the blood can easily absorb the digested food.

Lymph.

Apart from the blood, there is another important fluid in the body called *lymph*. It is colourless and is distributed all through the body by a system of spaces and ducts called the *lymphatic system*. One of its functions is to help in the transport of food, and there is in each villus a small lymphatic duct which absorbs food, especially fat, from the blood almost as soon as the blood has absorbed it from the intestine's contents. This tiny duct is called a *lacteal* (Latin: milky, because the fat in it makes the lymph whitish).

Conservation of Water.

By the time the large intestine is reached, almost all the beneficial substances have been removed from the food, and all that remains is a watery suspension of waste matter. As this travels towards the anus, water is gradually absorbed from it into the walls of the colon and rectum, and passed into the blood. The semi-solid waste or *fæces* (Latin: dregs), leave the body from time to time through the anus, which is controlled by a sphincter muscle, similar to the stomach sphincters, except that whereas the latter are involuntary the *anal sphincter* is mainly under conscious control by the brain.

The Cæcum.

This organ is well developed only in herbivorous animals, and is thought to be of use in the digestion of cellulose, which carnivorous animals are unable to break down.

Food-Storage in the Liver.

The liver is a gland. Blood from the intestine passes through it, and some of the food is removed and stored for later use. Waste material in the blood is here converted into *urea* and passed on to the kidneys, which remove it from the blood for excretion from the body in the urine.

Glands.

In this chapter several references have been made to glands. A gland (Latin: *glans*, a nut) is a group of cells which secretes a special chemical substance. There are two types, glands with ducts, which are mainly concerned with digestion and excretion (liver, pancreas, gastric, sweat-glands, kidney, etc.), and *ductless* or *endocrine* (Greek: filter) glands.

Ductless glands secrete substances directly into the blood which flows through them, and are the chief sources of hormones. They are of great importance in controlling the *chemical balance* of the body. The chief endocrine glands are the *pituitary*, just below the brain, the *thyroid* and *thymus* in the chest-cavity, and the *adrenal* (sometimes called the suprarenal) glands just above the kidneys.

The pituitary body is the most powerful ductless gland, because it controls the rate of growth and development of the body, and affects the activity of all the other glands. Defects of this gland may result in the animal being either a giant or a dwarf.

The thyroid gland also affects the development-rate, and the action of this and the pituitary gland are discussed on page 154.

The thymus is still not thoroughly understood. It seems to be specially important in early life, for it has been found to decrease in size as the animal becomes adult.

The adrenal glands produce *adrenalin*, which causes the blood-vessels to contract, increasing the blood-pressure. This condition often arises when an animal is frightened or enraged. Much adrenalin is secreted, and the animal becomes "keyed-up for action". Its hair stands on end, and blood rushes from the skin into the internal organs. The first of these conditions can be seen when a cat sees a dog, and the second when a person becomes "white with fear" or "livid with rage". Adrenalin is sometimes injected into the blood to control severe bleeding.

The pancreas, in addition to its function as a ducted gland, also produces an endocrine secretion called *insulin*, which is of great importance in the digestion of carbohydrates. Lack of insulin causes *diabetes*, a disease which can be controlled (but not cured) by careful dieting, to avoid taking in too much carbohydrate, and by the injection of insulin directly into the bloodstream at regular intervals.

Ruminants.

Some mammals have a digestive tract whose structure, in the anterior region (œsophagus and stomach), is much more complicated than that of the rabbit or of Man. These are the *ruminants*, of which cattle and sheep are common examples. Part of the œsophagus is greatly expanded into a storage-chamber called the *rumen* or paunch. Attached to this is another chamber called the *honeycomb-bag* (from its internal appearance, Fig. 76).

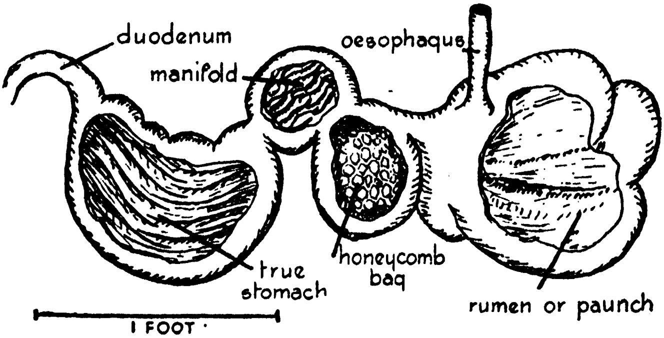


FIG. 76.—Part of digestive tract of a ruminant (sheep).

The animal gulps down its food into these two storage-chambers, where it is stored and softened until the meal is completed. The animal then takes a rest and brings back the softened food, in small amounts, into the mouth, where it is thoroughly ground up by the side-to-side movements of the lower jaw. After this process (chewing the cud), the food is again swallowed. This time it by-passes the paunch and honeycomb-bag, and enters the first part of the true stomach, where digestion proceeds in the normal way. The walls of these chambers of the cow's stomach are sold as tripe.

QUESTIONS

SECTION A.

1. Describe the difference in the condition of a piece of bread just before being eaten, and just before being swallowed. How are the changes caused?
2. Make a simple but fully-labelled diagram of the alimentary canal of either Man or the rabbit.
3. Write short notes on ptyalin, rennin, pepsin, insulin, bile.
4. Why can a man standing on his head swallow food? What type of muscular tissue would you expect to find in the intestine, and why?
5. Make a list of the glands with ducts in a mammal, including one gland not mentioned in this chapter. What is an endocrine gland?
6. What happens to food when digestion is completed?
7. What do you think may be the reason for the greater diameter of the large intestine compared with that of the small intestine? Why is it not practicable to take all our food in small-tablet form? (Such tablets containing all the necessary carbohydrate, fat, protein and vitamins could easily be prepared.)
8. Write an essay on vegetarianism.

SECTION B.

1. Compare the digestive system of the rabbit with that of Man, to show how the difference in diet is reflected in their structure.
2. Describe the digestive processes taking place in the stomach, stating the work of each of the main constituents of the gastric juice.
3. What is meant by "oral hygiene"? Why is it necessary for human beings, when animals seem to get along quite well without it?
4. Write a short essay on "Endocrine glands and their work".

CHAPTER X

BREATHING AND CIRCULATION IN MAMMALS

THIS chapter deals with the structures and mechanisms of the *respiratory* and *circulatory* systems of mammals.

Respiratory Organs.

The term "breathing", as used in ordinary conversation, refers only to that part of the process of respiration which deals with oxygen and carbon dioxide on their way to and from the place where they enter and leave the blood. The organs chiefly concerned are the *nose*, the passages connecting it with the lungs (*respiratory tract*), the lungs themselves, and the diaphragm.

The inner surfaces of the *nasal passages* are lined with a layer of moist skin (*mucous membrane*), richly supplied with blood-vessels, and bearing hairs which may be coarse near the openings (nostrils), but become extremely fine in the upper passages, which also contain sensitive nerve-endings able to detect odours. The nose filters, warms and moistens incoming air. If air is breathed in through the mouth instead of the nose these operations are not efficiently carried out.

From the nose the air passes to the back of the mouth (pharynx), where it crosses the path by which food is swallowed, and comes to the voice-box ("Adam's apple" or *larynx*) at the front of the throat. As explained on page 129, the epiglottis ensures that the trachea is closed during the swallowing of food. It is therefore impossible to inhale air and swallow food at the same time.

The trachea was described on page 125. It divides into two branches, each called a *bronchus* (plural: bronchi). The bronchus enters a lung and divides again into the *bronchioles*. These in turn divide into very small closed sacs called *alveoli*: and it is here that the blood comes into close contact with the air, being separated from it only by the thinnest of linings. The blood removes oxygen from the air and releases carbon dioxide into the air-space in the alveolus. The internal surface of the lungs is enormous (about a hundred times the total skin-area of the body), to enable the gas-exchange to take place quickly. In the rabbit, the lungs are more obviously lobed than in Man. The rabbit's right lung has four lobes, the left only two.

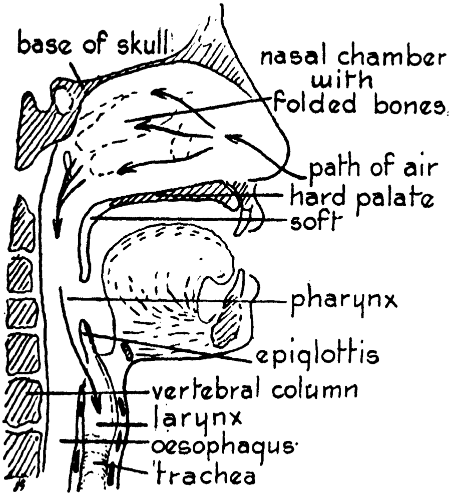


FIG. 77.—Section of face showing path of air in inspiration.

Mechanism of Respiration.

The diaphragm, which is found only in mammals, takes an important part in breathing. It is dome-shaped when at rest, but being very muscular is able to contract into an almost flat sheet. This brings its centre down, thus increasing the size of the chest-cavity above it. At the same time the ribs move upwards and outwards, making the chest-cavity still bigger.

Now, as the volume of a gas increases, its pressure decreases; so the air-pressure inside the lungs becomes less than that of the atmosphere outside, which accordingly pushes more air in to restore the pressure. This fills the lungs out so that their walls press against the inside walls of

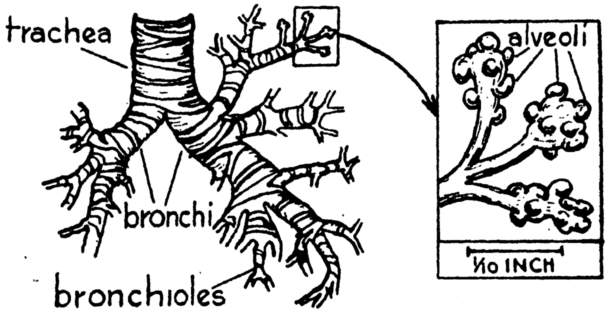


FIG. 78.—Small part of human lungs, with covering (pleura) removed.

the chest. Then the ribs and diaphragm return to their normal positions, and some air is forced out again.

In normal breathing, only about one-eighth of the air is changed each time, and this *cycle* of *inspiration* and *expiration* takes place about fifteen times a minute. By very deep breathing a man can increase his lung-capacity to about three hundred instead of two hundred cubic inches, and change about two hundred cubic inches of this each time. The difference in percentage make-up of the air entering and leaving the lungs is shown in the following table:

	INHALED	EXHALED
Oxygen	20.96	16
Carbon dioxide	0.04	4
Nitrogen	79.00	80

It will be seen from this that, while in the lungs, the air gives up about a quarter of its oxygen, and its carbon dioxide-content is increased a hundred times. It also gains a little nitrogen. As the body is very sensitive to the relative amounts of oxygen and carbon dioxide in the air it is not surprising that when several people are in a small ill-ventilated room the atmosphere soon becomes oppressive. A considerable amount of moisture is breathed out with the air (about a pint a day in Man), and in a confined space this adds to the discomfort.

The Voice.

The larynx has two folds of skin stretched across it from back to front, with a space between them called the *glottis*. These are the *vocal cords*. Their edges, bordering the glottis, have elastic ligaments in them, and when air passes between them they vibrate, in much the same way as when the neck of a rubber balloon is stretched tightly, and the air allowed to escape. The nasal passages amplify the sound on its way out.

All the mechanisms referred to above are controlled, some consciously, some unconsciously (page 240) by the brain.

The Blood System.

Blood is the means by which all the tissues of the body receive their oxygen and rid themselves of carbon dioxide and other waste substances. It has several other functions, which will be described later in this chapter, but on this account alone it is clear that, since oxygen can only enter the blood in the lungs, all the blood in the body must pass through the lungs at regular intervals. A man's body contains about nine pints of blood which all passes through the heart and lungs every two minutes or so.

Circulation of the Blood.

People nowadays are so familiar with the notion of blood circulation that you may be surprised to learn that it was not until 1628 that Sir William Harvey, a British doctor, proved that the blood does in fact travel round the body in a system of tubes, along which it is driven by the heart.

Structure of the Heart.

There are really two circulatory systems, and the heart is a double pump. It is divided down the middle into quite separate halves; the right side of the heart pumps blood to the lungs and back to the left side (*pulmonary* circulation). The left side of the heart pumps blood to all other parts of the body and back to the right side (*systemic* circulation). The left side of the heart is therefore necessarily a much more powerful pump: and this explains why the heart-beat is so much stronger on the left side of the chest.

Each side of the heart consists of two chambers: an upper thin-walled one (*auricle*) and a lower one (*ventricle*) with thick muscular walls. The entrance to each auricle is guarded by pocket-like flap-valves which prevent blood from going out again where it came in. Instead, when the auricle contracts, the blood is forced through a one-way valve in its floor, and into the ventricle beneath. As this is a very short journey, there is no need for the auricle to have very powerful muscular walls.

When the ventricle contracts, however, it has to force the blood through long tubes which offer great resistance, and so the walls of the ventricles are thick and powerfully muscular. The valve between auricle and ventricle is also very strong, to prevent blood from going straight back to the auricle. Strong cords attached to the flaps prevent the valve from being turned inside-out (compare the ribs of an umbrella). The valve on the right side is the *tricuspid* (Latin: three-pointed) as it has three flaps, and that on the left side is the *mitral* (mitre-like), having two flaps which give it, when closed, an appearance resembling a bishop's mitre.

Arteries and Veins.

Blood is carried by tubes of two kinds: *arteries* and *veins*. The arteries which carry blood away from the heart (that is, from the ventricles) are thick-walled and elastic: and since the blood in them is under pressure from the contraction of the heart, they are usually buried fairly deeply in the body-tissues, for protection. When an artery is cut, bright red blood spurts from it in time with the beating of the heart.

Veins, which carry blood to the heart (into the auricles), have much thinner, less elastic walls, because the pressure of the blood has been lowered on its journey, before it enters them. They are often found quite close to the surface of the body. Because of the reduced pressure in the veins, valves are required to prevent the blood from flowing in the wrong direction, especially when it has to flow upwards. These valves are pocket-like flaps of skin, and their action is seen in Fig. 79. When a vein is cut, blood flows steadily from it. The colour is less bright than that of arterial blood, because it contains less oxygen; but of course it brightens up a little in contact with the air (see page 144).

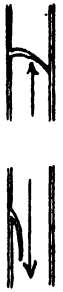


FIG. 79.—Valves in veins (arrows show direction of blood-flow

INQUIRY 62. Place the right hand, palm upwards, on the knee, and rest the finger-tips of the left hand lightly on the wrist, just behind the ball of the thumb. A rhythmic throbbing can be felt as the blood surges through the artery in the wrist. This surging is called the *pulse*.

INQUIRY 63. Bare the forearm, and allow it to hang limply. The veins will begin to stand out, because the blood has to travel against the force of gravity. Hold the arm above the head. The veins become less prominent as gravity helps the blood to move along them to the heart.

Capillaries.

Blood leaves the heart by arteries and returns by veins; so it must be transferred somewhere in the body from one to the other. This occurs in the tissues, and takes place through very fine tubes called *capillaries* (Latin: *capillus*, hair). The walls of these are able to contract and dilate slightly, thus controlling the blood supply to their own section of the body. It is the resistance of these capillaries which makes it necessary for the heart to apply a pressure of about twenty pounds per square inch, in order to force blood through the system.

INQUIRY 64. Place a young tadpole in a little water on a watch-glass and examine its tail, and external gills if present, under a microscope. The capillaries can be clearly seen, with the blood flowing through them. Notice how the red corpuscles (see p. 144), which in the tadpole are biconvex, have to squeeze through the fine capillaries.

If there is a really good microscope available it will be possible to examine the capillaries in the skin near the base of your finger-nail, by using powerful reflected light.

Pulmonary Circulation.

From the right ventricle blood is driven along the *pulmonary arteries* (Latin: *pulmo*, lung) to the lungs. The opening from the heart to the arteries is guarded by a valve. In the capillaries of the lungs the blood is *re-oxygenated* and gives up carbon dioxide and some water-vapour and nitrogen. It then returns along the *pulmonary veins* to the left auricle.

Systemic Circulation.

The left auricle contracts and forces blood into the left ventricle, from which it is driven into the *aorta*, the biggest artery in the body. From this, branches distribute it all over the body. A valve guards the opening to the aorta. Fig. 80 shows the main branches of the circulation.

After passing through the capillaries, where it loses most of its oxygen and takes up waste products, the blood is gathered by the veins and returns to the heart. On the way to the heart the small veins unite until, just outside the right auricle, there are only three main veins: the small *coronary* vein, which returns blood from the heart-walls themselves (which need a blood supply just as any other organ), and two large veins, the *precaval* (superior vena cava) which returns blood from the upper half of the body, and the *postcaval* (inferior vena cava) which returns

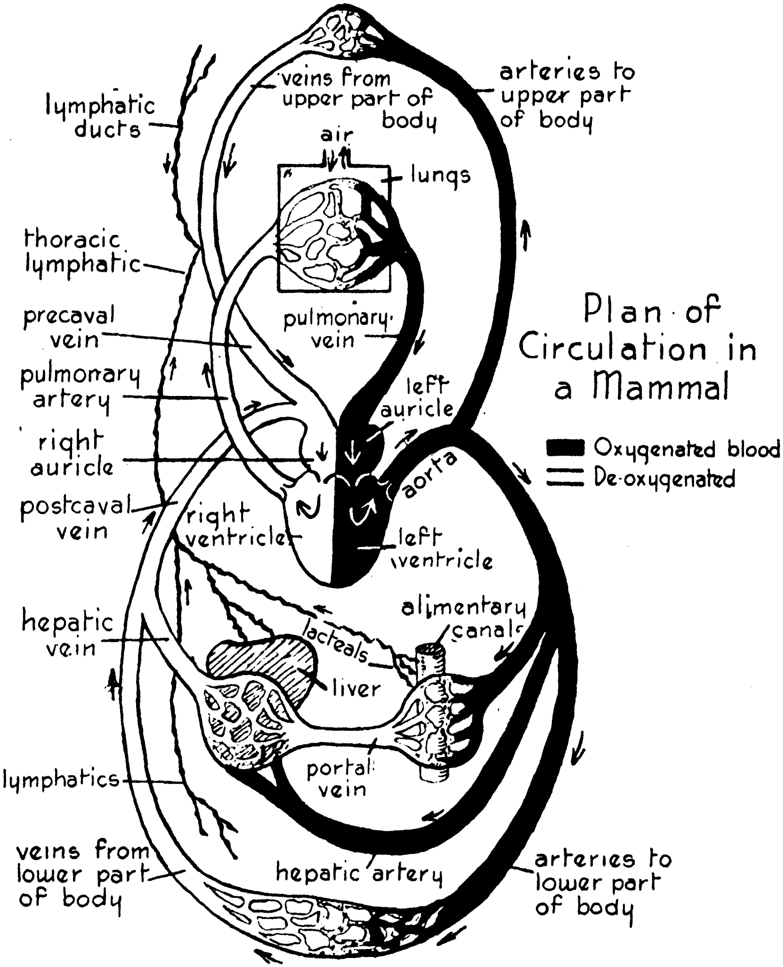


FIG. 80.—Main course of blood circulation in a mammal (diagrammatic).

it from the lower half. These veins lead the blood into the right auricle, which in turn forces it into the right ventricle, and so the circulation is complete. The blood has travelled right through both the pulmonary and systemic circulations.

The Portal System.

Blood coming from the alimentary canal differs from other venous blood, because besides losing oxygen and gaining carbon dioxide, it has also picked up the products of digestion of food. It cannot therefore immediately take its place in the general circulation. Instead, it goes to the liver, where it is distributed throughout the organ by capillaries. The vein which carries this blood is peculiar in having capillaries at both ends. Such a vein is called a *portal vein.* In mammals there is only this one portal system, the *hepatic* (Greek: *hepar*, liver) *portal system.* A frog has also a renal portal vein.

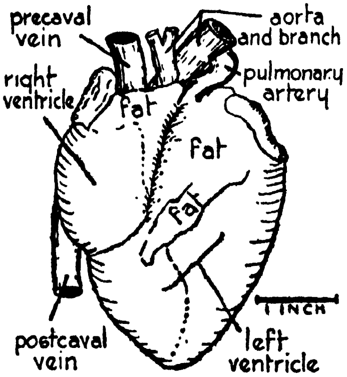


FIG. 81.—Sheep's heart seen from ventral side.

From the liver, after treatment (page 131), the blood is picked up by another set of capillaries and carried to the postcaval vein.

It should be noted that the pulmonary artery differs from all the others in containing deoxygenated blood, which is otherwise found only in veins (and is consequently often called "venous" blood); whereas the pulmonary vein is the only one containing bright red "arterial" blood.

At this stage, having reviewed the main features of the blood-circulation of mammals, it will be useful to examine a mammalian heart. The sheep's heart is convenient, being bigger than the rabbit's, and fairly easy to obtain. It is advisable to tell the butcher that you wish the main vessels to be left attached, as otherwise they will be cut off too close and the heart may be damaged.

INQUIRY 65. Examine and draw a sheep's heart from the ventral side, as in Fig. 81. Note the layer of fat which acts as a cushion when the heart is beating. The position of the partition dividing the right and left sides is seen by the groove running diagonally from top left (animal's left) to bottom right. Thus the apex (pointed end) of the heart is occupied by the left ventricle alone.

INQUIRY 66. Attach a glass tube by a piece of rubber tubing to a water-tap. Insert the glass tube into each of the heart-vessels in turn, tying a piece of twine round it in each case, and turn on the water. It will be found that some vessels will allow the water in, when it will rush out through another vessel; in these cases you have attached the tube to a vein. In other cases the vessels will not allow water to enter; this is an artery. Make notes of the nature of each vessel.

Now label the vessels of the heart with the help of your notes and Fig 84. Insert long pieces of glass tubing into the pulmonary vein and artery, tying the vessels on to the tubes. Pour water into the vein till it can be seen in both tubes. On squeezing the ventricle the level of the water will drop in the vein-tube and rise in the other, owing to the action of the tricuspid valve.

INQUIRY 67. Cut open the left ventricle and auricle, and examine the valves. Note that the action of the right side of the heart is not affected. Now open the right side, and examine the valves.

In life, the two auricles contract together, followed by the two ventricles. In a man, this cycle of operations, called the heart-beat, occurs about seventy times a minute, or more than 100,000 times a day.

The Blood.

Blood is a tissue. It consists of a clear, straw-coloured liquid called *plasma*, in which float several types of living cells. The plasma contains dissolved salts, proteins and enzymes, as well as other substances such as hormones (page 130) which may be secreted into it from various parts of the body.

The living cells may be coloured (erythrocytes) or colourless. In mammals the erythrocytes are red flat discs, thicker at the edges than in the centre. Their red colour is due to a chemical in them, called *hæmoglobin*, which is a compound of iron and a protein, and has the property of absorbing oxygen and giving it up again with great ease. When it absorbs oxygen, it turns bright scarlet and is called *oxyhæmoglobin*. When it loses it again it becomes a dull purplish red. There are, in Man, about 5,000,000 *red corpuscles* ("little bodies") in every cubic millimetre of blood; one drop of blood would provide two corpuscles for every man, woman and child in the British Isles, and leave a few million corpuscles over.

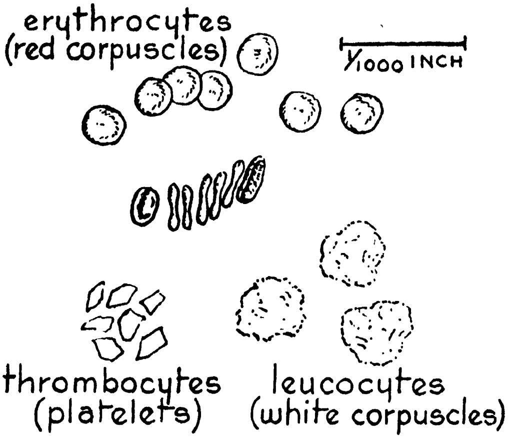


FIG. 82.—Bodies forming part of human blood.

The colourless corpuscles are of several types, but we may group them together as *leucocytes* and *thrombocytes*. The leucocytes are often called *white corpuscles*, and they are much less numerous than the red. They are capable of independent movement, like amœba (page 181), and can thus escape from the capillaries into the tissues. Their main work is to attack and destroy germs which invade the blood and tissues; thus the yellow matter which is seen in pimples consists largely of masses of leucocytes which have died in the struggle against infection. There are about 5,000 leucocytes in a cubic millimetre of blood, but their number is much more variable than that of the red corpuscles.

Thrombocytes are flat plates, sometimes called *blood platelets*, and take an important part in the clotting of blood when exposed to air. There are about 250,000 of them in a cubic millimetre of blood.

In general, blood is slightly viscous ("thicker than water"), and slightly more dense than water.

Clotting of Blood.

When blood escapes from a blood-vessel it soon changes into a solid. The process takes place in stages, and can be watched by leaving sheep's blood in a glass vessel. First the blood becomes syrupy, then jelly-like: and finally it separates into two distinct layers—a solid *clot*, containing all the corpuscles, and a clear, almost colourless, liquid called *serum*.

The process is very complicated, but consists partly in the changing of a protein in the plasma, called *fibrinogen*, into threads of solid *fibrin*, which entangle all the other solids of the blood and so separate them from the rest of the plasma. The change takes place through the action of an enzyme secreted by the platelets: but this can only begin to act when another enzyme, imprisoned in the walls of the vessels, is released by injury.

Blood Transfusion.

In 1914 it was discovered that by adding potassium citrate to fresh blood it could be prevented from clotting. This made it possible to develop the technique of *blood transfusion*, by which a person who has lost a great deal of blood, or whose blood has become defective by certain diseases, can be supplied with blood from another person, the donor. Many thousands of lives were saved in this way in the 1939–45 war. It is usually only the plasma which is transferred. Tests have to be made beforehand, as some types of plasma cannot be mixed without clotting.

Blood Groups.

All human beings have blood belonging to one of four groups. These are called groups A, B, AB, and O. A person with Group O blood can safely receive blood from any donor. A person with Group AB blood can safely give blood to any other person, and is called a universal donor. Apart from these two cases, the donor and receiver must belong to the same *blood-group*, otherwise their blood will clot when mixed.

Formation of Blood Corpuscles.

All the corpuscles of the blood are formed in the marrow of the bones. They live for about three weeks, and when worn out are taken to the liver, where the iron is extracted and returned to the bones, to be used again. There is an organ near the liver, called the spleen, which is believed to play some part in the formation or destruction of the corpuscles.

Functions of the Blood.

The main functions of the blood are as follows: to carry oxygen to the tissues; to remove waste products; to carry dissolved food from the alimentary canal to all parts of the body; to distribute heat through the body; to carry the secretions of the ductless glands (hormones) about the body; to destroy disease germs; to seal up wounds by forming scabs.

The part played by the blood in excretion is described on page 269.

The Lymphatic System.

As mentioned on page 131, there is, in addition to the blood system, another circulatory system in the body which is less obvious because the liquid in it is colourless, and because it is not so closely confined within narrow tubes. Nevertheless it is important and we should know at least a little of its work. In general, it acts as an auxiliary to the blood. There is a continual interchange of food, waste materials, and white corpuscles between the blood-plasma and the lymph. It bathes all the parts of the body which are not reached by capillaries, especially in the larger cavities, such as those round the heart, the lungs, and the intestine. Its function of absorbing fats from the blood in the intestines has been described already. It is driven round the body mainly by the squeezing-action of the general body-muscles, but in a few places it passes through special lymph-ducts with muscular walls, called lymph-hearts.

QUESTIONS

SECTION A.

1. Describe what happens to air when passing in through the nose. What is the correct method of breathing?
2. Describe the action of the diaphragm and ribs in breathing. What happens when a person hiccoughs?
3. Why is it unwise to wear tight clothing about the neck and chest? Why should bedroom windows be left open at night?
4. Write notes on the following: trachea; alveolus; capillary; plasma.

5. Contrast the structure of an artery with that of a vein, and show how each is related to its function.
6. What is a portal system? Draw a simple diagram of the systemic circulation in a mammal.
7. Describe in detail the structure of the sheep's heart.
8. Describe the structure and functions of the blood.

SECTION B.

1. Describe how air is carried from the atmosphere to the lungs, pointing out how the structure of each part of the respiratory tract is related to its function.
2. Distinguish (*a*) the conscious and unconscious, and (*b*) the voluntary and involuntary movements associated with respiration. Point out which of the movements, normally unconscious, can be made conscious at will.
3. Describe the advantages of the mammalian system of respiration over that of the frog.
4. State, with reasons, what change you would expect in the rate of blood circulation in the following conditions: (*a*) up a high mountain; (*b*) sleeping; (*c*) in a faint.

CHAPTER XI

GROWTH

ALL organisms pass through a stage in their development during which they increase in size. In some cases, as when the adult organism is itself only a single cell (amœba, page 181), this process of *growth* may consist only in increasing the quantity of essential materials already present in the cell. In most cases, however, growth is accompanied by a great increase in the number of cells. The human body, for instance, contains countless millions of cells, which have all developed from the single cell with which each person begins life.

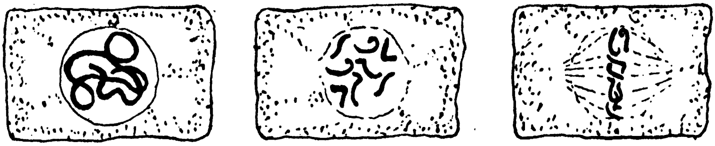
Cell-Division.

It may seem strange at first that a process which increases the number of cells in the body should be called cell-division; but the reason is that the increase is brought about by existing cells dividing into halves, followed by the growth of each daughter-cell, until there are two cells, each as big as the single cell from which they came. Thus the process may be correctly called cell-multiplication or cell-division.

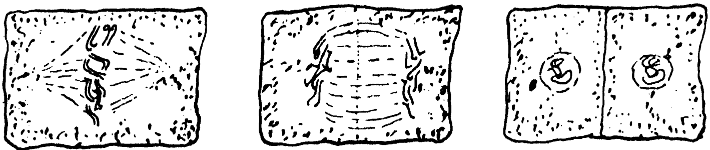
Every organism has an individuality which distinguishes it from every other organism: from its parents, from other offspring of those same parents, and so on. If this individuality is to be preserved it must be implanted in every newly-developed cell of the organism. This is ensured by the fact that in every new cell there is a part of the nucleus of a previous cell of the organism. Moreover, when a nucleus is dividing, it does so in such a way that every feature of the nucleus is evenly shared between the two daughter-nuclei. To understand the importance of this, we must learn a little of the structure of the nucleus, though this subject is so complicated that we can only glance at it in passing. We shall refer to it again when discussing heredity in Chapter XXII.

Nuclear Structure.

A very powerful microscope reveals that the nucleus of a cell, especially at the time when it is ready to divide, is not simply a structureless mass of jelly, but contains several distinguishable parts, of which the most important are a number of threads, which occur in pairs, of definite size and shape. They are called *chromosomes* (Greek: coloured bodies), because when the cell is stained, they take up the dye very readily. The number of these pairs of chromosomes, and the shape of each pair, is constant for all the cells of an organism (for exceptions, see page 278), and, usually, for all the members of a species. Thus Man has twenty-four pairs, the rabbit twenty-two, the fruit-fly four, the crayfish one hundred: and among plants, the onion has eight, maize ten, and the pine-tree twelve.



1. Chromatin-thread forms in nucleus
2. Thread breaks up into chromosomes
3. Chromosomes forms central disc



4. Each chromosome splits lengthwise
5. Halves separate, partition forms
6. Daughter-cells fully organised

FIG. 83.—Stages in cell-division.

When the nucleus divides *each chromosome splits right down its length*, and each of the two daughter-nuclei gets one-half of it. Thus the daughter-nuclei have the same number of pairs of chromosomes of the same shape as each other, and as their parent-nucleus.

Differentiation.

Although the individuality of an organism is in some way stamped on every one of its cells, there is room for great variation in the shape, size and structure of its cells, according to the work they have to do. It has been seen in Chapter II (page 23) that in a flowering plant all the different types of cell are produced from a common undifferentiated tissue, and develop their characteristic differences as they grow. This common tissue which gives rise to all the others is called *meristem* (Greek: dividing). The cells it produces may change very little (e.g. parenchyma) or very much (e.g. xylem), but each contains in its chromosomes something which identifies it as a cell of that particular organism.

Differentiation follows a precise plan, so that by the time the organism is adult it has all the necessary tissues in the right places, and the complete individual is recognizable as a member of the same species as its parent or parents. This in itself is a very remarkable fact: that organisms as widely different as a buttercup and an elephant should each start as a single cell, hardly distinguishable from each other even under the microscope: and by a process of sure and steady growth, differentiation and development, turn into almost exact replicas of the organisms which produced them.

This *continuity of species* is a matter of common observation, and is one of the most firmly established facts in biology. On it depends our confidence that when a hen-egg hatches a chicken will come out of it; whereas out of an alligator-egg will come a young alligator; that when we plant an acorn we may be sure, if it grows at all, it will produce an oak-seedling, and so on.

Repair and Regeneration.

An organism has not only to grow and develop to the adult stage: it must continually replace tissues which are wearing out. By the time a person is twenty-one years of age every one of the millions of cells in the body has been replaced: and to do this while preserving the identity of the individual obviously demands that the replacement of tissues should follow a very precise plan.

It is therefore normally a slow and gradual process; but sometimes, especially in simple animals such as the hydra (page 184) or the earthworm (page 188), parts of the body which may have been completely lost through injury can be *regenerated* at a fairly quick rate, so that the organism is able to survive even severe mutilation.

In more highly organized animals and plants this power of regeneration is still present, but only to a very slight degree. In our own bodies, for example, broken bones, if properly cared for, will grow together again: finger-nails which have been trapped will fall off and be replaced: and damage to the skin and underlying tissues will be repaired unless it is very extensive.

Growth-Rate.

The rate of growth and development varies greatly in different types of organism. As a general rule, the more highly organized a creature is the more slowly it develops; but there are many unexplained factors involved. Thus, most insects pass through their entire life-cycle in something less than a year: but there is in North America an insect, the seventeen-year cicada, whose larval stages (page 153) last for seventeen years, while the adult stage lasts only a couple of weeks.

Perhaps the most influential single factor in growth-rate is *temperature*. In all organisms there is a minimum temperature below which growth and development cannot take place: and, within limits, increase of temperature increases the growth-rate. This explains why food-plants such as rhubarb, tomatoes and strawberries can be "forced", or made to grow sooner and more quickly by growing them in heated greenhouses. It also explains why crops generally appear earlier in the south of Britain than in the north, a fact which is easily verified by travelling south or north in early spring and comparing the state of the trees and fields along the route.

Birds hatch their eggs by keeping them warm with their bodies; and it is well known that if hen-eggs are removed from the roost and kept cool they will keep for long periods without any development occurring inside. In this case, however, it should be remembered that many hen-eggs are infertile, and would not hatch even if the hen sat on them in the normal way.

In the preservation of food by *refrigeration* advantage is taken of the fact that organisms cannot grow without heat. Food "goes bad" because bacteria, which are always present in the air, find it a good source of food. They settle on it and quickly grow and multiply if the temperature is favourable. As their number increases the heat produced by their respiration raises the temperature of their surroundings, and their rate of development rises still further so that there are soon enough of them to poison the food with decomposition-products of their metabolism.

The damage can be prevented by keeping the food so cold that the bacteria are *inactivated.* Note that they need not be killed; they are dangerous only when allowed to multiply unchecked. Fresh milk, for example, always contains millions of bacteria per cubic centimetre. Most of these are harmless to human beings; but at a suitable temperature each bacterium may reach maturity and divide into two in fifteen minutes. At this rate, one bacterium will become nearly seventy thousand in five hours, and the products of their respirations will turn the milk sour.

Other Factors Affecting Growth.

Even at suitable temperatures it is clear that growth cannot take place in the absence of the materials which are to be incorporated in the new tissue. Consequently, *food* is an essential factor in growth. Organisms with an abundant supply of food normally grow more quickly than those which are partially starved. It is also important that the food be available at the right stage in the organism's development; thus, a child who is deprived of food in early years will be stunted, and good food in adult life cannot entirely repair the damage caused in youth.

Fresh air and *sunlight* enable most organisms to get the best out of their food, and therefore affect the growth-rate.

In higher organisms, *exercise* of the tissues promotes their development and so increases their growth-rate.

All these factors combined tend to make country-bred children bigger and stronger than their counterparts in overcrowded industrial areas.

Growth-Hormones.

There are certain chemical substances which are capable of affecting directly the rate of growth of tissues. These substances are produced by the organism in very small quantities, either at the place in the organism where they are to act, as is usually the case in plants, or in an endocrine gland (page 132) from which they are carried by the blood to the site of operation, in the case of animals. The substances are called *hormones* (Greek: exciters). Their effect is very specific; for example, in flowering plants the hormone known as *auxin* produces quite different effects in the root from those it produces in the shoot. In the root, it make the cells grow short and wide, while in the shoot it makes them grow long and thin (see page 229).

In animals, hormones are produced at the proper time to ensure development of certain parts of the body, such as the organs concerned in reproduction. Hormones are also of great importance in controlling the process of *metamorphosis*.

Metamorphosis.

It is usual among vertebrates to find that the young animal has the same fundamental structure as the adult, and its development is a steady increase in size, and possibly in complexity, without any drastic change in appearance. Thus, it is easy to recognize a chicken as a bird, a baby as a human being, a puppy as a dog, and so on.

In some types of vertebrates, however, notably the amphibia (page 171) and in many lower animals, such as the insects, it is common for the young organism to have an entirely different structure from that of the adult. Sometimes there are several stages of development which would seem entirely unrelated to each other if we were not able to observe the actual transition from one stage to the next.

As an example, the tadpole is so different in structure and appearance from the frog, that one would not suspect that the frog had spent its early life as a tadpole, but for the fact that tadpoles may be seen changing into frogs.

Development which proceeds in a series of widely different stages in this way is called *metamorphosis* (Greek: changing shape). Some examples are considered in detail in Chapters XIII, XIV and XXIII. For the present we need only consider one feature of the metamorphosis of the tadpole. The forms which an animal assumes before becoming an adult are called *larval* forms: so the tadpole is the larva (Latin: mask) of the frog. Its metamorphosis into a frog is caused by two hormones, *pituitrin* and *thyroxin*, produced by the pituitary and thyroid glands respectively. If these fail to supply their secretions in the right places at the right time, metamorphosis will not occur. Thus, by removing these glands from a tadpole, it is possible to produce a giant tadpole as big as a frog and capable of laying eggs. The Mexican *axolotl*, which is often sold as a curiosity by aquarium dealers, is such a giant tadpole whose thryoid secretion, although present in the body, does not work. If thyroxin is injected under its skin it will change into a salamander, of which it is the larval form.

Cretinism.

The growth and development of humans also is affected by hormones. People whose thyroid secretion is very deficient become stunted and coarse-featured, with large heads and small bodies. Such people are called *cretins* (French: *chretien*, Christian, to emphasize that they are human beings, and entitled to the care and protection of normal people), and are usually mentally deficient. They can be completely cured by carefully regulated doses of thyroid extract, obtained from the thyroid glands of animals.

Size-Limitations.

Have you ever wondered why there are no flies as big as crows: worms as big as pythons: or why there should be no land-animals as big as the enormous whales and basking sharks found in the seas?

The maximum size of a particular organism depends on many factors. The size which can be attained by an animal which breathes only through its skin is severely limited, because the surface of a body does not increase as rapidly as its volume. Thus, a three-inch cube has twenty-seven times the volume of a one-inch cube, but only nine times its surface-area. In an animal which breathes through its skin, therefore, a size is soon reached at which there is only just enough surface for adequate respiration, and any further increase in size would result in suffocation. This explains the limited size of worms, insects, and many other aquatic forms of life.

There are also mechanical limitations on size. Thus, the air would not support great weights of tissue—large animals must have a supporting skeleton; if a worm reached a diameter of several inches it would be flaccid ("floppy"), like a sausage-skin partly filled with water. Similarly when a whale, whose huge bulk is normally supported by the sea-water, gets washed up on shore, its limbs are simply not strong enough to hold it up or move it, and it is completely helpless.

It is less easy to find obvious explanations for the vast range of size among plants, from bacteria less than a thousandth of a millimetre long to great forest-trees, some of which are the biggest living things on earth.

Size-Control by Selective Breeding.

Through the centuries the average size of livestock has been noticeably increased by careful breeding. Horses, cattle and sheep are now much bigger than were their wild relatives, because for centuries the biggest and healthiest types have been selected for breeding, and their living-conditions have steadily improved. Reference was made on page 111 to the Flemish Giant rabbit, which is another example of selective breeding.

With dogs, the influence of selective breeding on size is very striking. Dogs as different in appearance as the toy pomeranian and the St. Bernard are all varieties of the same species.

QUESTIONS

SECTION A.

1. Describe how cell-division takes place, and how, in the process, the fundamental characteristics of the organism are preserved.
2. Write short notes on (*a*) chromosomes, (*b*) meristem, (*c*) regeneration.
3. Describe how outside influences affect the growth of organisms.
4. Describe how the growth of an organism is controlled from inside the organism.
5. What are hormones? Describe the importance of growth hormones in metamorphosis.
6. Name three factors which help to determine the maximum size of organisms, and give one example of the operation of each.
7. Name two cases in which it is desirable to increase, and two in which it is desirable to reduce, the growth-rate of organisms and state how this is carried out.
8. "Which of you by taking thought can add to his stature one cubit?" Discuss to what extent it is possible to control the size of organisms, and give reasons for the smallness of the range of possible control.

SECTION B.

1. Describe how the individuality of an organism is preserved during its development and growth.
2. What is meant by continuity of species? How is it ensured?
3. Discuss the factors which affect the growth-rate of an organism.
4. Write a short essay on the work of growth-hormones.

CHAPTER XII

THE SEED AND THE SOIL

EXCEPT for vegetative reproduction (page 102) a flowering plant normally begins life (as an individual, distinct from its parent) as a small group of cells, called an *embryo*, enclosed, along with a supply of food, in a protective cover. The complete structure is called a *seed*, and in the next few pages we shall see something of different types of seeds and how they begin to develop into recognizable reproductions of their parent plants.

Dicotyledon Seed—The Broad Bean.

There are two main types of seeds, dicotyledon and monocotyledon, which give their names to the two groups of flowering plants. We shall examine examples of each type.

The seed of the broad bean plant is a very convenient example of a dicotyledon seed, because of its large size. Before being examined it should be soaked in water for several hours.

> INQUIRY 68. Dry a soaked bean-seed with a cloth and examine the seed. The tough outer covering is called the *testa* (Latin: shell). At one end there is a dark-coloured scar, the *hilum*, where the seed was attached to a stalk in the pod. Just above one end of the hilum is the apex of a small triangular swelling, and at this same end of the hilum is the *micropyle* (Greek: very small hole). It is too small to be seen easily, but if the seed is squeezed at the sides, water will come out of the micropyle; because that is where it went in, the rest of the seed-coat being waterproof.
>
> Draw two views of the bean to show its shape and external features.

> INQUIRY 69. Fill a small medicine-bottle with dried peas or small beans, and stand it in a pail of water. In a few days' time the seeds will be so swollen with water that they will burst the bottle.

The next step in investigating the bean-seed is to remove the testa and examine the seed's internal structure.

> INQUIRY 70. With a sharp-pointed knife or scalpel make a shallow cut right round the seed, from one end of the hilum to the other. The testa may now be slipped off in one piece. Examine it, noting its toughness. It can now be seen that the triangular swelling on its outer surface corresponds with a little pocket inside, and that a projecting portion of the seed rested in this pocket.

The projecting portion of the seed is the radicle, or future root of the plant, and is part of the embryo. The rest of the embryo is hidden but will be exposed at the next stage in the examination of the seed.

> INQUIRY 71. Draw the seed with testa removed, showing the radicle. Note that the two fleshy halves of the seed, though in very close contact, can be gently forced apart with the fingers. Do this, and examine the rest of the embryo, which will remain attached to one of them. Draw the half with the embryo attached.

The cream-coloured masses which make up the bulk of the seed are the *two seed-leaves* or *cotyledons* (Greek: cup-shaped objects) which supply the embryo with food, and on whose account the seed, and thus the whole plant which develops from it, is called a dicotyledon (Greek: *di-*, two).

In the broad bean, the food is stored inside the cotyledons, making them thick and fleshy. This is not the case in all seeds (page 160). Unfortunately the word "cotyledon" is rather poor as a descriptive name for the seed-leaves, but it has been used for so long that to change it would cause more trouble than it would save. The term "seed-leaf", too, is not very apt in the case of the broad bean, but in other seeds which we shall examine it proves quite a useful descriptive term.

On separating the cotyledons, it will have been seen that they enclose between them a short curved structure, continuous with the radicle. This is the *plumule* (Latin: little feather), and on examination with a hand-lens is revealed as a pair of miniature leaves, the first true leaves of the plant. The plumule is

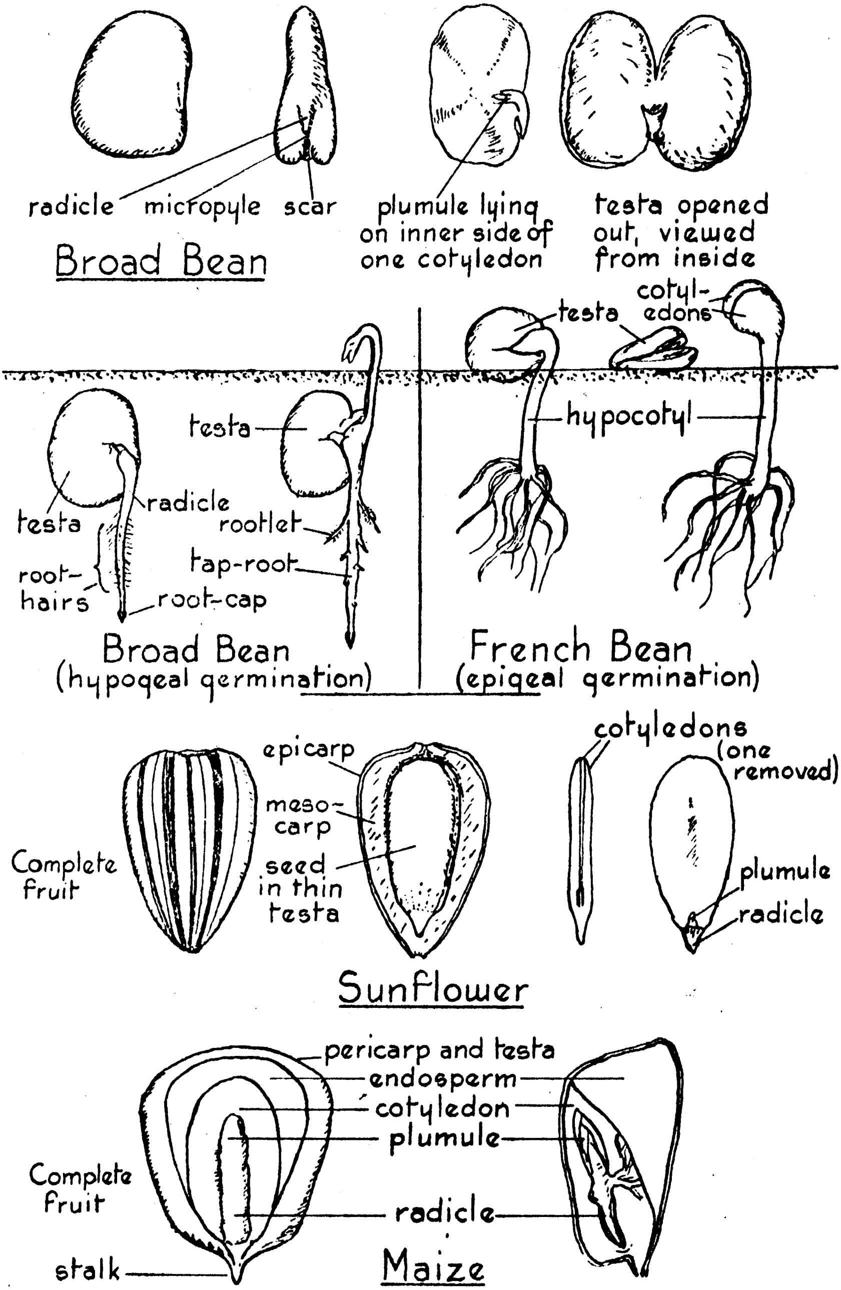


FIG. 84.—Seed-structure and germination.

connected with the radicle by an extremely short stalk, which is also attached to the two cotyledons and divides the embryo into a shoot-region (plumule) and a root-region (radicle).

Other Dicotyledon Seeds.

The Sunflower. The striped, heart-shaped sunflower "seed" is really a complete fruit (see page 263). Unlike the bean, which has several seeds in one pod, the sunflower has only one seed in each fruit, so the part which corresponds to the bean-pod is simply a thin covering round each seed. When this hard covering is removed, the seed is seen to be more symmetrical than the bean-seed: there are two planes in which it may be divided into equal halves, whereas in the bean there is only one. The radicle protrudes at the pointed end of the seed, and dissection shows that the plumule points vertically upwards between the two cotyledons.

Castor-Oil Seed. The hilum and micropyle are hidden under an outgrowth called the *caruncle.* In some plants this is brightly coloured or otherwise attractive to animals, and so helps in the dispersal of the seeds (page 266). When the testa is removed, the cotyledons are still hidden by a thick layer of fleshy tissue. This is called *endosperm.* On cracking it open it is found to be hollow, and the thin papery cotyledons are attached to its inner surface, from which they absorb nourishment for the embryo.

Germination of Dicotyledons.

Broad Bean. Under suitable conditions (page 163) a seed will begin to develop into a full-grown plant. The early stages of this development are called *germination* (Greek: *germen,* offspring).

> INQUIRY 72. Line the inside of a glass jar with a layer of blotting-paper and fill it with enough sand, or, preferably, glass wool, to keep the paper in place. Insert two or three soaked beans, spaced out, between the paper and the glass. Try to place each seed with its hilum in a different position from the others. Pour water into the jar, leave it in a warm dark place, and record the progress of the seeds for about three weeks, adding water from time to time as needed.

The first sign of germination is the lengthening of the radicle, which pushes its way out of the testa and begins to grow downwards. It does this, even if the seed is planted upside-down (page 229).

Shortly after this the plumule emerges, lifting up the triangular flap of testa which covered the radicle and growing upwards. The tip of the plumule remains curved, so that it is the more mature and robust part of the stalk which leads the way, dragging the delicate leaves after it. This part of the stalk is called the *epicotyl* (Greek: above-the-cotyledons).

When the plumule first emerges its leaves are a very pale yellow: and as long as they remain in the dark they remain so. In normal conditions, however, with the seed planted in soil, the upward growth of the epicotyl soon brings the plumule out into the light and it begins to turn green.

All this activity and manufacture of new tissue requires food, and as the process goes on the testa becomes wrinkled, showing that the cotlyedons inside it are gradually shrinking as they give up their food.

As the radicle continues to grow it gives off branches (rootlets) which first appear as little knobs under its surface and later push their way through. This is *endogenous* development, and is typical of roots (page 37).

When the young shoot reaches the light and turns green, its leaves open out and gradually take over the work of providing food for the plant in co-operation with the roots. The cotyledons, as their work is completed, shrivel up and die away.

When germination occurs as just described it is called *hypogeal* germination (Greek: below-ground), because the cotyledons remain in the soil.

The Sunflower. In this case, the radicle develops as before, but the shoot is carried up by rapid growth of the part of the stalk below the cotyledons (the *hypocotyl*, compare above). This means that not only the plumule, but also the cotyledons, are dragged up and exposed to the light. The cotyledons bring up with them the testa, which eventually falls off. The cotyledons, when most of the food in them has been used up, turn green and leaf-like and assist in the early photosynthetic work of the seedling. Thus, in this and similar cases, the term "seed-leaves" is very apt.

It is not generally realized that this *epigeal* (above-ground) type of germination just described is far commoner than hypogeal germination. It can be recognized by the fact that the hypocotyl is usually red, and first appears above the soil-surface as a loop.

> Inquiry 73. Germinate some cress-seeds, as instructed on page 15, but examining them at intervals during the process. Find out whether the germination is epigeal or hypogeal.

In cases of epigeal germination, the seed-leaves are usually simpler in shape than the true leaves, and so easily distinguished however long they persist.

Castor-Oil Seed. Germination is similar to that of the sunflower; but, as the cotyledons are distinct from the food-store, they are able quickly to assume the appearance and function of ordinary leaves. As a result, by the time they emerge from the soil they are already quite large.

Monocotyledon Seed—Maize.

The maize "seed", like the sunflower, is really a complete fruit; but in this case the part corresponding to the bean-pod is so closely attached to the testa that it is almost impossible to remove them separately. The seeds require about two days' soaking before examination, and it often helps if the outer skin is pricked with a needle before soaking.

The grain has a light-coloured oval patch on one side. Under this is the embryo, with the radicle pointing to the stalk of the grain, and the plumule pointing in the opposite direction. They are so small that they must be carefully levered up with a needle and examined with a hand-lens. They are attached to a single cotyledon, which partly overlaps them. Behind the cotyledon is a hard amber-coloured mass of endosperm.

All grass plants are monocotyledons, and have seeds whose structure is similar to that of the maize; but most of them are too small to be examined conveniently.

Germination of Monocotyledon Seed.

The radicle and plumule of the seed are each encased in a protective sheath. The radicle soon breaks through its sheath, but the plumule retains its sheath until it has pierced the soil-surface. At a very early stage, adventitious roots grow out from the base of the stem, soon replacing the true roots. As the plant develops, adventitious roots arising further up the stem peg it down, like stay-ropes.

Food Reserves in Plants.

Seeds usually contain starch; this is easily shown in the case of the larger seeds, such as the bean, by cutting the cotyledons and smearing the cut surface with iodine solution. A dark-blue colour shows the presence of starch. The fact that wheat-seeds contain starch is shown by testing wheaten flour with iodine.

Many seeds contain oil instead of starch. The caster-oil seed, sunflower, cotton and flax seeds are commercially valuable for the oil they contain (sunflower seeds are used as poultry-food; linseed oil comes from the flax plant).

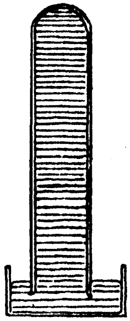


FIG. 85.—Apparatus for anaerobic respiration of seeds.

Conditions for Germination.

It will have become obvious that *water* plays a big part in germination. Indeed, germination cannot take place without it, and seeds may be preserved for years, alive and unchanged, by depriving them of water.

Warmth is also needed. Seeds will not germinate at very low temperatures. This is one of the main reasons why so many plants germinate in the spring, when the soil-temperature is raised by the first few weeks of spring sunshine.

Since the process of germination involves the expenditure of much energy, we should expect that *respiration* must take place. This is, in fact, the case. Normally the respiration is aerobic, but if free oxygen is not available anaerobic respiration occurs, the seed breaking down the food reserves to obtain the necessary energy (page 94).

> INQUIRY 74. Introduce a few sprouting seeds into the tube seen in Fig. 85. The tube is full of mercury. Keep the apparatus in a warm place for a week. Gas will appear at the top of the tube. Blow a little limewater into the tube through a curved pipette. It will float up to the top of the tube and turn milky, showing that the gas is carbon dioxide. The seeds have been respiring, despite the absence of free oxygen.

The breaking-down of food reserves in anaerobic respiration is made possible by the production of enzymes in the seed during the early stages of germination. Germinating seeds can therefore be used to induce a similar break-down of sugar solution into alcohol on a large scale. This is why *malt* (barley-seeds which have been killed at a very early stage of germination) is used in the brewing of beer.

Further Development of the Plant.

The process of germination is complete when the food reserve in the seed has been used up, and the shoot has turned green. After this, the plant, if it is to develop further, must make its own food, with the aid of sunlight, from carbon dioxide and mineral salts in solution. The carbon dioxide is obtained from the air, and the water and salts from the soil.

The chemicals present in soil-water have been described (page 92). The physical and chemical nature of soil itself plays a big part in the development of the plant.

Soil.

Soil is a mixture of chemical compounds. The main constituents of soil (i.e. the things which make it soil), are *humus, sand, clay, chalk, moisture and air.*

Humus is decaying organic material—the waste products and remains of animals and plants. The fact that it is decaying shows that it also contains enormous numbers of living bacteria (page 206). One gram of soil may contain 100,000,000 living creatures.

INQUIRY 75. Boil some milk in each of two conical flasks for ten minutes. Plug the necks with cotton-wool. Divide a sample of soil into two parts, and bake one part thoroughly to sterilize it. When cool, drop some of the baked soil into one flask, and some of the fresh soil into the other, and renew the cotton-wool plug. After three days in a warm place, the milk containing the fresh soil will be sour, from the action of the bacteria, while the other remains fresh, provided no bacteria entered it while you were introducing the baked soil.

Sand and Clay are compounds of silicon, aluminium and oxygen with sodium, potassium and other elements. Few people realize that, after oxygen, silicon is the most abundant element in the earth, and aluminium the next most abundant.

The difference in size of their particles is more important than the chemical differences between sand and clay as soil-constituents. Clay has microscopic particles, so that if stirred up with water many of them remain suspended, forming a *colloidal solution*. Clay holds a great deal of water, which makes it plastic. Earthenware is moulded clay which has been baked to drive off the water. It is important to note that though there is a lot of water in clay it does not allow water to pass through it easily—thus clay can be used to line water-tanks and reservoirs. A basin-shaped layer of clay under the earth often forms a natural underground reservoir, from which the water can be obtained by sinking artesian wells.

Sand consists of much larger particles which allow water to drain through them quickly.

INQUIRY 76. Half-fill a tall gas-jar with soil, and fill up with water. Cover and shake vigorously: then allow to settle. The biggest particles (gravel and coarse sand) sink to the bottom, followed by the fine sand and silt. The clay remains as a cloudy suspension in the water, and the humus floats on the surface.

INQUIRY 77. Arrange two filter-funnels on a stand, half-fill one with damp sand, and the other with clay. Pour water into the funnels and compare the rates at which it passes through.

Chalk is calcium carbonate. Its main uses in the soil are to break down the clay by causing its particles to join together into groups: and to neutralize the acidity of humus which makes the soil sour.

INQUIRY 78. Make a suspension of clay in water. Make another one, using limewater instead. The second suspension will become clear, as the lime makes its particles join into groups which sink. Limewater is calcium hydroxide (not carbonate) and this substance, known as slaked lime, is often added to soil to "lighten" it when there is too much clay in the soil.

Moisture. The reason for the high water-content of clay is mainly the greater capillarity which in its turn is made possible by the small size of the spaces in the particles. This results in the clay not only retaining rain-water which falls on it, but also drawing up water from the earth below it.

INQUIRY 79. Fill a wide glass tube with dry sandy soil, and another one with dry clay soil. Stand them on a folded piece of muslin or flannel in a shallow dish of water. Leave for at least a week, taking care that the water in the dish does not dry up. Compare the heights to which the water rises in the tubes. Note that it rises faster in the sandy soil, but soon stops, and is slowly overtaken by the water in the other tube.

Soil which feels dry to the touch usually contains enough water for the needs of plants. If this "dry" soil is heated gently it will lose weight, as can be shown by weighing it before and after heating.

Too much water in the soil is a serious disadvantage to flowering plants as it excludes air from the roots which suffocate. It also encourages the growth of parasitic fungi (page 201) and upsets the balanced action of the soil-bacteria.

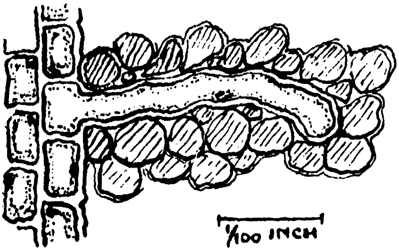


FIG. 86.—Root-hair in close contact with soil-particles.

Air. There should be a constant exchange of gases between the soil and the atmosphere, and this is possible only if the soil contains plenty of air-spaces. Clay has not enough air-spaces. On the other hand, if the soil is too loose it will lose water both by evaporation and drainage; so there should not be too much air-space. Sandy soil has this defect.

The ability of soils to allow air to pass through them may be shown by attaching to the stems of the two funnels in Inquiry 68 long glass tubes full of water, with rubber tubing and a clip at the bottom of each. The funnels are filled up with soil, and the clips opened. The water in the tube attached to the sandy soil quickly runs out, but the other only trickles very slowly out, because air cannot get through the clay into the tube to replace the water.

Types of Soil.

These are named according to which of the main constituents is present in greatest proportion. A *clay soil* contains about forty per cent clay. A *sandy soil* has fifty to seventy per cent sand and less than ten per cent clay. Between these extremes is *loam*, which may be a sandy loam or a clay loam. A mixture of clay and chalk is called *marl*. All these soils contain humus, and the proportion of it determines the richness of the soil and often the darkness of its colour. The proportions of sand and clay may be judged from Inquiry 67. The humus-content may be found by thoroughly drying the soil with very gentle heat, weighing it, and then heating strongly and weighing again. The heat will destroy the humus, and this will be shown by loss of weight. This experiment can give only approximate results. (Why?)

Origin of Soil.

All soil has been formed by the breaking-down, or *weathering*, of rocks. This process is caused mainly by the action of frost, which cracks the surfaces of the rocks. Wind, rain and sun, and rivers also, play their parts in breaking-up and transporting the material. The average depth of soil over the land-surface of the earth is less than six inches; a very remarkable fact when we remember that the teeming life on the earth is so dependent on the soil. There are parts of the earth covering many thousands of square miles, which are known to have been fertile in the past but are now deserts because the soil has all blown away.

Soil and Subsoil.

The nature of soil has been described. Below it is usually found a material which, having no humus in it, is lighter in colour. It contains much bigger particles than the soil itself, and is in an intermediate stage in the change from solid rock to soil. This is *subsoil*, and is important as the material from which more soil will be made as the top layers blow away and as the roots of trees grow deeper.

Below the subsoil is solid rock. If the soil and subsoil are removed, more soil and subsoil will be formed from the rock. This may lead you to ask: "Why, then, are there great expanses of rock in many places?" This is because in those places the weathering process is obstructed, chiefly by the hardness of the rock; but in a place where weathering has already occurred it goes on continuously.

Leaching.

Many of the mineral salts required by plants are soluble in water. Humus is very porous; so is sand; and therefore unless there is a fair amount of clay in the soil to retain the water the important salts will be washed out of reach of the plant's roots. This is called *leaching*. It is very important in farms which are situated on hill-sides, because the salts are often washed away from the farmland into the valleys. Hill-farming is therefore a precarious occupation.

The Work of Earthworms.

The earthworm is described in detail in Chapter XIV. Here we are only interested in its effect on the soil. Darwin, in a fascinating book on earthworms, stated that there may be 80,000 earthworms in an acre of soil. They are continually burrowing and swallowing soil, and the effect of this is to churn up the soil and keep it in good condition by periodically "bringing it up for an airing", and maintaining air-passages through it. Earthworms will move more than ten tons of soil in an acre of ground in one year, and will bring up enough soil in five years to renew completely the soil to a depth of one inch.

Cultivation.

The purpose of cultivating soil is to make sure that it has the right texture and contains the proper chemicals for producing good crops. By ploughing, to mix up its constituents, and by adding lime, which by weathering is converted into chalk, the soil is lightened and sweetened. A fine top-surface makes it possible to control the loss of moisture, so fields are levelled and smoothed by harrowing. Natural or artificial manures are added to maintain the correct proportion of humus.

These are only a few of the many processes by which farmers have for centuries improved the land and persuaded it to bear ever-increasing crops. Science is not confined to text-books and laboratories.

An interesting link between ploughing and the subject of seed-germination is the fact that after a field has been ploughed there is often a crop of plants of a particular type, such as charlock, which appears as if by magic in the wake of the plough, springing up in a few weeks after the field is turned over. This is because the seeds of the plant were already in the soil, but not until it had been ploughed were the conditions just right for that particular type of seed to germinate.

Ecology.

Ecology (Greek: study of home) is the study of the effect on the lives of organisms, of the surroundings in which they live. It is closely connected with the nature of the soil. In the desert, where the "soil" lacks one of its essential constituents, water, plants cannot flourish. As a result, animals, which, as we have seen, depend on plants for their food, are not found in the desert. In polar regions, the temperature is too low for plant roots to function, and the only plants found are lichens, which can survive with a minimum of mineral salts but do not reach great size.

Some aspects of the ecology of our own islands are considered in Chapter XXV.

QUESTIONS

SECTION A.

1. Draw a series of labelled diagrams showing the structure of a bean-seed.
2. Draw diagrams showing four stages in the germination of a broad bean.

3. Compare the structure and germination of maize with that of the broad bean.
4. Describe the methods employed for the protection of the tender tip of the plumule during germination of (*a*) broad bean, (*b*) sunflower, (*c*) maize.
5. Write short explanatory notes on the following: hilum; micropyle; radicle; plumule; testa.
6. Explain in detail the importance of (*a*) the testa, and (*b*) the epicotyl in a broad-bean seed.
7. Compare the features which distinguish epigeal from hypogeal germination and discuss the advantages and disadvantages of each.
8. Name the main constituents of soils, and state their importance in the lives of the plants which grow in them.

SECTION B.

1. Compare a named dicotyledon seed with a named monocotyledon seed, under the headings (*a*) Structure, and (*b*) Germination.
2. "A seed is a living individual." Discuss this statement.
3. Make an analysis of the soil in the neighbourhood of your school, and state, giving reasons, whether it is a good agricultural soil.
4. Devise an experiment to show that germinating seeds breathe oxygen.

CHAPTER XIII

AMPHIBIANS—THE FROG

Most boys, at least, should be familiar with the term "amphibian", from its use to describe aircraft which can take off from both land and water. In biology the word has a rather restricted meaning; it is applied only to animals which can *breathe* freely both on land and in water. Thus, a seal, which spends most of its time in the water, is not an amphibian, because it has to hold its breath under water, just as we do.

In this country the amphibia include frogs, toads and newts. Adult toads and newts confine themselves fairly constantly to one medium—land in the case of the toad, and water for the newt. In their young stages, however, frogs, toads and newts are all completely aquatic (water-living). In this chapter we consider the frog, which as an adult is truly amphibious, although it would drown if held permanently under water. Its underwater breathing mechanism is not efficient enough to support its respiration for very long periods.

Frog-Spawn.

The eggs of the frog are found in shallow ponds and ditches, clustered in masses of jelly, which appears as a spherical envelope around each egg. When the eggs are first laid this envelope is very thin, but in the water it soon swells up until its diameter is several times that of the egg inside it. The slippery jelly protects the eggs from birds and fish which would otherwise eat the eggs. It also ensures moist conditions for the eggs, even during temporary drying-up of the ditch: and eventually it serves as food for the young tadpoles which hatch out from the eggs. Frog-spawn is usually plentiful during the last two weeks in March.

The egg, which can be seen in the middle of the transparent globule of jelly, is spherical, the top half being black and the lower half pale-grey or white. This colour-scheme has a two-fold advantage. As daylight strikes only the upper half of the egg its colouring tends to smoothe off what would otherwise be a sharp contrast between the lighted and unlighted halves. This is an example of *camouflage*, and makes the eggs less easily seen by fish and other marauders. In addition, the dark colouring of the upper half enables it to absorb the radiant heat of the sun, which soon causes it to begin the complicated process by which it develops into a tadpole.

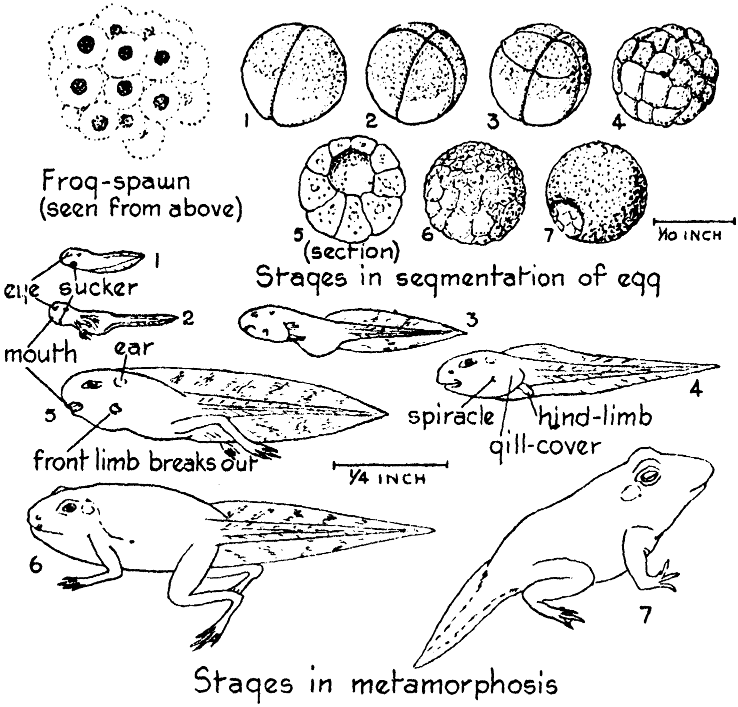


FIG. 87.—Development of Frog.

Segmentation.

About two hours after being laid each fertilized egg is suddenly surrounded by a vertical groove which marks it off into two cells. An hour or so later a second groove encircles it at right-angles to the first, producing the four-cell stage. Next, a groove appears just above the equator, dividing the egg into four small upper, and four larger lower cells. The upper cells are much more active and are called the animal cells, while the lower cells are heavy with food reserves in the form of yolk, and are called vegetal cells. After this, division proceeds rapidly and irregularly, leading to a big increase in the proportion of animal cells so that the object begins to look like a very small blackberry.

A space then forms inside the sphere, and the animal cells begin to grow over and enclose the vegetal cells. Soon afterwards the spherical outline changes to an elongated shape which is soon recognizable as a tadpole, still enclosed in the jelly.

INQUIRY 80. The above process is more easily followed in the egg of the newt, which does not have a thick layer of jelly. Freshly-laid newt's eggs (which will be found singly, attached to curled-up leaves of water-weeds) should be examined at regular intervals, in a white shallow dish containing some of the water in which they were laid. Make a timetable of the progress of the changes as far as it can be followed with a hand-lens. Keep a second sample near a warm radiator, and compare the rates of development.

Tadpoles.

The tadpoles (Old English: toad-like head) of all amphibia are so much alike that it is a constant source of wonder that they produce such varied animals as frogs, toads, newts and salamanders. The frog-tadpole, when first formed, is a helpless-looking fish-shaped creature less than a quarter of an inch long, curled up inside its egg-membrane. Suddenly, with a series of wriggles, it begins to fight its way out of the jelly and, once free, swims about until it finds a convenient leaf of pond-weed to which it attaches itself by means of a ventral *sucker*.

At this stage a hand-lens will reveal that the tadpole has three pairs of fine feathery outgrowths just behind its head. These are the *external gills* by which it breathes dissolved oxygen. The water near the surface of a leaf is rich in oxygen, given off in photosynthesis (page 97), and the tadpole hangs very still so that this enriched water can play on its gills.

INQUIRY 81. Examine the external gills of a tadpole under the microscope. The blood can be seen pulsing through them in time with the animal's heart-beats.

When the egg-yolk inside its body is used up, the tadpole begins to nibble with a pair of newly-formed *horny jaws* at the leaf on which it hangs, or at the jelly of the frog-spawn. The food is dealt with by a long coiled alimentary canal which is easily seen through the transparent body-wall. About this time it should be possible to distinguish the *eyes* and, between them, a pair of primitive nostrils (*olfactory pits*).

As the tadpole thrives on its vegetarian diet (developing an obvious paunch) its external gills are gradually absorbed and replaced by four pairs of *internal* gills with gill-covers, like those of a true fish (page 300). These gills are less easily damaged but would not be suitable in the early stages, when the tadpole is not active enough to force a current of water over them. Two swellings appear at either side of the base of the tail, and gradually develop into a pair of *hind-limbs*, the first frog-like features of the larva.

Soon the animal begins to forsake its vegetarian ways and seek fleshy food. Its horny jaws are shed, revealing *bony jaws with teeth.* At this stage it may make war on its brothers and sisters, nibbling pieces out of their tails. If one tadpole dies, the others soon swoop on it and eat it up. This change from a herbivorous to a carnivorous diet is accompanied by a reorganization of the digestive system, involving a reduction of the intestine to about one-third its original length.

As metamorphosis proceeds, the internal gills are being replaced by a pair of *true lungs*, and the animal comes to the surface occasionally to try out these new breathing-organs.

The *front limbs* appear as buds and slowly develop, and the animal is now obviously a miniature frog, except for its long tail which is slowly absorbed into the body as a form of food. By the time the frog is about three-eighths of an inch long it is able to forsake the water for short periods, trying out its lungs and limbs.

> INQUIRY 82. Trace the development of tadpoles kept in the laboratory. They should be fed with chopped worms. Remove debris regularly. Casualities are often heavy, and dead tadpoles should not be left in the water.
>
> INQUIRY 83. Observe under the microscope the circulation of blood in the capillaries of a tadpole's tail (see page 140).

The Adult Frog.

The frog is a cold-blooded vertebrate. Unlike birds and mammals, whose blood remains at a constant temperature despite changes in the temperature of their surroundings, the blood of a frog has the same temperature as the surroundings. The animal therefore does not need the protection of fat or hair. Cold-blooded animals, however, are often sluggish in their activities, and the frog is no exception. In winter it buries itself in mud and becomes completely inactive. At other times it will stay for hours in one position, apparently dozing; but if disturbed it will escape with a mighty leap in an unpredictable direction.

External Features.

The most striking features of the frog are its long powerful hind-limbs, its curiously humped back, and its broad flat head with bulging eyes (Plate II). When in the water it often floats with only its eyes and nostrils exposed. The skin is olive-green or brown, and is kept moist by a layer of mucus (slime) produced by special glands in its surface. The moisture is necessary so that the skin can absorb *dissolved* oxygen, even when the frog is on dry land. Scattered about the skin are special *pigment-cells* which, by automatically expanding and contracting, cause the frog to adjust its colour, or more accurately its shade to that of its surroundings. The skin does not at any time bear hair or scales.

The Head. The frog's head is squat, with a wide mouth. When this is closed the small nostrils above it are also closed, making the mouth air-tight. This is because the animal has to "swallow" air forcibly into its lungs, which have no diaphragm to help their expansion: so it takes a gulp of air, closes its mouth and nostrils, and forces the air into its lungs by contracting the floor of its mouth. When its mouth reopens, the natural elasticity of the lungs forces out the stale air, as out of a balloon. The inner lining of the mouth is very important in respiration, absorbing oxygen directly into the blood and giving off carbon dioxide.

The eyes are large and not set in bony sockets. The upper lid is almost immovable, and there is no structure corresponding to the lower lid of a mammal's eye: instead, a special *third eyelid* (present also in birds, page 305), which is transparent, can be drawn up over the eyes.

The backs of the eyeballs project into the roof of the mouth, and the frog makes good use of them in pushing food down its throat. This gives it a most comically smug expression after it has captured a fly or worm. The inside of the mouth is lined with a carpet of lashing *cilia*, microscopic whip-like cells which help to waft food down its throat.

The teeth are small and directed inwards. They are all alike. There are no teeth on the lower jaws, but there are two extra patches of them well inside the roof of the mouth. The frog does not chew its food, but uses its teeth only for holding its prey, which it prefers to swallow whole.

The tongue is fastened at the *front* of the mouth. It is sticky, and can be shot out to a distance of about an inch. This explains why unwary flies in the vicinity seem, to an observer, simply to disappear without any apparent cause. The flick of the tongue is too quick to be seen without keen and patient observation.

The ears are visible behind the eyes as two circular patches of tight skin. These are the eardrums. The frog has no "outer ear" (page 249).

The animal has no neck, and to that extent is slightly streamlined.

The Trunk and Limbs. The ventral surface of the body is light-coloured and soft. The dorsal surface, which is darker (camouflage again) is humped over the prominent sacral bones (see below). The frog has no tail.

There are four limbs, built on the pentadactyl plan (page 121). The two front limbs are short, and each bears only four fingers. The missing digit corresponds to the thumb in Man. During the breeding-season the male frog develops a horny pad on the inner side of its two first fingers.

The hind-limbs are longer than the rest of the body and have powerful muscles which account for the animal's jumping prowess. It is these muscles which, in the case of the edible frog, bred in large numbers on frog-farms, are considered a delicacy in some countries. The feet are webbed, and each has five long toes which spread out when the frog is swimming and enable it to exert a powerful thrust against the water. This technique was used during the war by "frogmen", equipped with rubber paddles on their feet by which they were able to swim rapidly under water.

> INQUIRY 84. As adult frogs are fairly easily obtained from March to October, there should be no difficulty in observing all the features described above. They should be released after examination, as they are not comfortable in a small aquarium.

Inside a Frog.

There is no need, for our purpose, to study the internal structure of the frog in great detail, but it is important to see how it is built to carry out its way of life and how it differs from the mammals.

General Structure. All the main systems (page 125) may be described as simpler versions of the corresponding systems in mammals. The respiratory system has been described already, including some reference to the skin.

The skeleton, which replaces the wholly cartilaginous skeleton of the tadpole, consists of a mixture of bone and cartilage. The skull is a light structure with several large holes in it, and differs strikingly from the heavy bony mass common in mammals. The vertebral column has only nine vertebræ, all much alike in shape and size, except for the sacral, whose large transverse processes reach out to the ends of the pelvic girdle. Ribs are represented by small pads at the ends of the transverse processes on seven of the vertebræ. The pectoral and pelvic girdles are shown in Fig. 88. (See also Plate II.)

The fore-limb skeleton is also seen in Fig. 88. Note the single bone in the forearm, called the radio-ulna, and compare with the standard plan (page 121). In the hind-limb, the tibio-fibula, again a single bone, has a groove down it which suggests that two distinct bones may have fused together.

The *muscular system* resembles that of mammals (page 121).

The *nervous system* resembles that of mammals, to be described on page 237.

The chief features of the *circulatory system* are the existence of *only one ventricle* in the heart (compare page 138), and the very plentiful blood-supply to the skin (*cutaneous circulation*) made necessary by the importance of the skin in breathing.

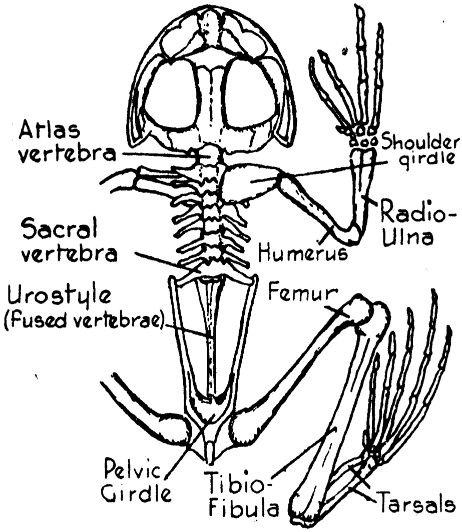


FIG. 88.—Frog's skeleton.

The single ventricle receives blood from both auricles: de-oxygenated blood from the right auricle, and oxygenated blood from the left. The mixed blood leaves the ventricle by a single vessel on the right side, called the *truncus*. (Compare trunk-line in a telephone system.) Branches lead off to the lungs and skin (pulmo-cutaneous), the main body-circulation (systemic) and the brain (carotid), in that order. It follows that, if the blood is not completely mixed during its short stay in the heart, the de-oxygenated blood will go to the lungs and the oxygenated blood to the brain, which has most need of it.

This system is less efficient than that of the birds and mammals but is quite adequate for the frog, which is a less highly-developed creature.

There is a lymphatic system essentially like that in mammals (page 131).

The structure of the blood closely resembles that in mammals, except that the red corpuscles are thin at the edges and thick in the middle (compare Fig. 82).

The *digestive*, *reproductive* and *excretory* systems all end in a single exit, the *cloaca*, through which solid and liquid waste and eggs or sperms are shed.

The *sexes* are separate—that is, any one frog is either male or female. At the breeding-season the male frog clasps the female round the waist from behind, taking a firm grip with the help of the pads on the first fingers of the front limbs. After a time the female lays a batch of eggs, and as they enter the water sperm from the male is shed over them. The two frogs then separate and take no further interest in their offspring.

Croaking. Frogs are dumb except at the breeding-season, when they make harsh sounds—especially the male. In marshy districts this can be quite a nuisance, especially as it occurs throughout the night and keeps people awake.

Toads and Newts.

The toad is more ungainly than the frog, with shorter limbs and a dry warty skin. It is not so good a swimmer, and its movements generally are slower than those of a frog. There is no truth in the stories that the toad squirts poison from its mouth, or that handling the animal causes warts, or that it "wears a precious jewel in its head". The toad lays its eggs in strings. Some foreign species of toads take great care of their offspring. Many gardeners encourage toads in their greenhouses as they help to reduce the number of pests.

The newt is a very graceful streamlined animal, with a prominent fish-like tail which is at least as long as the body. The adult animal has weak limbs and rarely leaves the water. The eggs, laid singly, are elliptical and by tilting them the yolk can be seen to roll from one end to the other.

QUESTIONS

SECTION A.

1. Describe the development of the tadpole from hatching to the completion of metamorphosis.
2. Describe the segmentation (cleavage) of the frog's egg, and state the sources of the energy required for the purpose (diagrams).
3. Describe the external and internal features of the frog's head, as they can be observed by inspection, and show how they are suited to the animal's habit of life.
4. Draw the pectoral girdle, and one side of the pelvic girdle, of a frog.

5. Describe, with the aid of a simple sketch, the main course of the blood-circulation of a frog.
6. Describe the breathing mechanisms of an adult frog, stating how they work (*a*) on land, (*b*) under water.
7. How does a frog capture and swallow its food? Of what does its diet consist?
8. Compare the external features of a frog with those of a newt.

SECTION B.

1. Compare the warm-blooded and cold-blooded types of blood-system, stating the advantages and disadvantages of each.
2. Describe how the structure and life-history of the frog enable it to fit perfectly into its environment.
3. Compare the ear of a frog with that of a mammal, and suggest possible reasons for the difference in structure.
4. Trace the change in breathing mechanism used by the frog from the hatching stage onwards, showing how each type is suited to the frog's environment at the time.

CHAPTER XIV

SOME LOWLY ANIMALS

THE animals we have studied so far have been vertebrates, that is, possessing backbones; but by far the majority of the animals on the earth do not have backbones. They are called the Invertebrates, and some of them form the subject of this chapter. Others are described in Chapter XXIII.

All-in-one-cell Animals.

We have seen that, to maintain its existence, an animal must engage in many activities, the most important of which are called the primary vital functions (page 4). In all the organisms we have studied already each of these functions is mainly the concern of some particular organ or organs, each containing millions of cells (page 7).

There are some animals, the Protozoa (Greek: first animals), each consisting of only one cell, which has therefore to carry out all these functions. Thus you may consider such an animal as extremely simple, or extremely complex, according to whether you are thinking of its one-celled structure, or its many functions all looked after by the same single cell.

Before reading further you should re-read pages 3 to 9.

Amœba.

Amœba is a unicellular animal found on the beds of ponds and streams where it spends its life slowly crawling over the mud in search of food. It is very small, being just visible to the naked eye as a greyish speck.

INQUIRY 85. From a sample of water containing amœba, draw up one specimen into a fine pipette, and transfer it to a cavity-slide (i.e. a microscope-slide with a slight depression in the centre).

Cover with a cover-slip, and examine first with low power then with high power. The need for a cavity-slide points out that amœba is three-dimensional.

Under the microscope amœba is seen to have a constantly-changing shape and so is often described as shapeless, meaning "having no *fixed* shape". It is a blob of protoplasm whose outer surface (ectoplasm) is transparent and slightly stiffer than the interior (endoplasm), which is granular (filled with specks). As the animal changes its shape, these two forms of protoplasm are constantly being converted into each other. Careful inspection of the endoplasm reveals that its granules are moving around, showing that the endoplasm itself is fluid. This condition reminds us of the cooling drop of molten wax referred to in Chapter I.

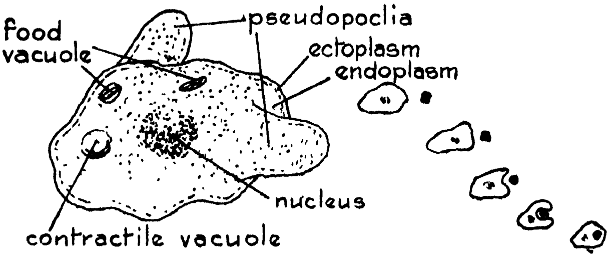


FIG. 89.—Amœba, showing also the method of food-capture.

Amœba *moves* by "oozing" part of its body in one direction, the projection thus formed being called a *pseudopodium* (Greek: false foot). The rest of the body-substance then simply flows along in the same direction, filling-out the pseudopodium again. By repeating the process the animal travels along.

Inside the endoplasm several features can be distinguished. The most prominent is the *nucleus* which, seen by transmitted light, looks darker than the rest of the endoplasm. If the animal is watched for a few minutes a small bubble will be seen to grow in the endoplasm, burst through the ectoplasm, and then begin to form again. This is the *contractile vacuole*, and is believed to help in the *excretion* of waste.

One or more other vacuoles will be seen in the endoplasm. These may be of various colours, because they contain food in various stages of digestion. They are called *food-vacuoles*.

As the amœba has no mouth you may wonder how the food comes to be in the endoplasm. Fig. 89 shows the stages in the capture of food. The prey, a water-flea or other very small organism, is trapped between two developing pseudopodia, which meet round it, and so it is drawn into the interior of the cell. Digestive juices are then secreted round it by the endoplasm, and so the food-vacuole is formed. When all nutriment has been absorbed from the food, the amœba rids itself of the remains by simply flowing away from them.

Respiration is carried out by the simple process of absorbing dissolved oxygen from the water all over the surface of the ectoplasm and passing carbon dioxide into the water in a similar way. There is no blood system.

The *reproduction* of amœba occurs in what seems a very simple way. When the animal reaches full size the nucleus divides into two and the protoplasm is redistributed to the two new nuclei. The two resulting individuals separate and begin to grow to the size of the original one. Thus, provided it escapes being destroyed by violence, amœba does not die; instead, it becomes incorporated in its offspring.

Spore-formation. If there is danger of the pond drying up, amœba forms round itself a thick resistant coating, and in this condition it can survive being without water, or even being blown about as dust. When suitable conditions return the case splits open and not one but many small amœbæ emerge, having been formed by division during the *resting-stage.* The thick-walled condition is called a *spore.*

Amœba *responds to stimuli.* Thus, it will retreat from the prod of a needle, from extremes of temperature, etc., and will move towards food. It can distinguish between real food and "imitation" food such as bits of blotting-paper.

To sum up, amœba shows all the primary vital functions and therefore is an organism. It feeds on complex substances (living organisms) and cannot make its own food from carbon dioxide and water. Among plants, this is true only of parasitic types: but amœba is free-living. Therefore it cannot be a plant and must be an animal.

Many-celled Animals.

All animals which are not protozoa are called Metazoa* (Greek: later animals).

The simplest of these are built on the plan of a simple sac, the interior of which is a digestive cavity. The wall of the sac is a double layer of cells. The outer layer is the *ectoderm* (Greek: outer skin) and the inner layer is the *endoderm* (inner skin). They are called the *Coelenterates* (Greek: having a sac-like digestive cavity).

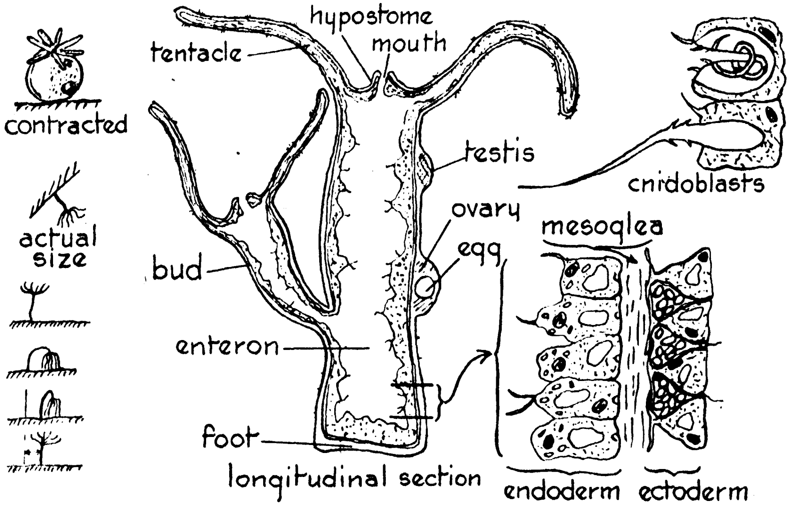


FIG. 90.—Hydra.

Hydra.

Hydra is an example of the simplest types of coelenterates. The many kinds of jellyfish are also coelenterates, but are more highly developed.

Hydra is a small fresh-water animal which, when extended to its full size, is about half an inch long. It is like a very simple tree, the "trunk" being the cylindrical sac which forms the main part of the animal, and the "branches" consist of from five to eight *tentacles* (Latin: touching-organ) which project from the top of the body, like the fingers of a glove (Fig. 90), (Plate VI).

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* The Sponges aae sometimes placed in a group of their own, called the Parazoa, district from both the protozoa and the metazoa.

The base of the trunk is a flat sticky disc, the *foot*, by which hydra attaches itself to a support. The other end of the cylinder is a conical *hypostome* (Greek: under-the-mouth), and at the apex of this is a hole—the *mouth*.

> INQUIRY 86. Examine hydra with a hand-lens in a petri-dish. Touch it with a blunt needle, watch it contract suddenly and slowly recover. Try to observe it catching water-fleas or other small animals.

Structure of the Ectoderm. The ectoderm of hydra contains several types of cells, each carrying out a special function in addition to its general one of forming part of the body-wall. The animal thus shows *differentiation of cells*: and along with this *specialization* of structure there is a sharing-out of the functions among different types of cells. This is called *division of labour*.

The main ectodermal cells are the *muscle-tail cells* which form the outer wall, and help to produce movement of the body. They are conical, with the base of the cone facing outwards. At the inner end each cell has two thread-like muscle-tails, which lie pointing to the head and foot respectively. When they contract they make the body shorter and thicker.

In the spaces between these tapering cells are undifferentiated cells called *interstitial* (space-filling) cells. These can change, as the need arises, into any of the types of cell found in the ectoderm.

Scattered in the ectoderm, especially on the tentacles, are batteries of very specialized cells called nematoblasts (Greek: *thread-cells*). Each of these cells is an elaborate weapon. The cell is a sac full of liquid, in which is coiled a long hollow tube. At the outer edge of this *nematocyst* (Greek: thread-sac) is a tiny "bristle" which acts as a trigger. When this *cnidocil* is touched the walls of the cell suddenly contract, shooting out the coiled thread, which in some cases has a barbed end, while in others the tip breaks off after piercing the prey, and poison is forced in through the hollow tube. In this way the hydra stuns and holds its prey while the tentacles carry it to the mouth.

Nerve-cells are also present in the ectoderm. They are star-shaped flat cells, connected by their points to each other and so forming a network covering the inner surface of the ectoderm.

Messages pass along this net, enabling the animal to respond as a whole to a stimulus which may only touch it at one point. (See page 223.)

Asexual reproduction. When food is plentiful and conditions are good, some ectodermal cells develop into little swellings which soon become recognizable as young hydras, just like the parent in everything but size. Eventually these *buds* become detached from the parent and lead a separate existence. This is asexual reproduction, there being no formation or fusion of gametes (see below).

Sexual reproduction. If living conditions become difficult, due to lack of moisture or food, a different type of reproduction occurs. Two swellings appear on the side of the body: the upper is called the *testis* or *male reproductive organ* (sometimes several develop at once) and the lower one is called the *ovary* or *female reproductive organ.* Reproductive cells called *sperm* swim out of the testis and one of them fuses with the egg-cell of the same or a nearby hydra. The fertilized egg, or *zygote,* grows a thick resistant coat, and falls to the bottom of the pond, where it awaits suitable conditions and then develops into a hydra similar to its parent or parents.

The process just described is an example of sexual reproduction. It always involved the fusion of two distinct cells, the *gametes*, of which one, the male, is usually small and active, and the female larger and stationary, carrying a store of food. The two gametes commonly, but by no means always, come from different individuals. This is called *cross-fertilization* (page 282).

The Mesoglea and Endoderm. The inner layer of the body-wall is separated from the ectoderm by a thin layer of jelly called the *mesoglea* (Greek: middle glue) which helps to support the animal and so acts as a primitive skeleton. The mesoglea is not made up of cells but is secreted by the cells of the ectoderm and endoderm. In a jellyfish this layer may be several inches thick.

The *endoderm* contains muscle-tail cells similar to those of the ectoderm, but in this case the tails extend round the cylinder instead of up and down. When these contract, therefore, they make the body longer and thinner.

The inner ends of these cells may bear *flagella* (Latin:

whip-lashes), which are like large cilia and cause the water in the digestive cavity to circulate. This brings the food into contact with other muscle-tail cells which have pseudopodia at their ends and absorb food, forming food-vacuoles like those in amœba.

The endoderm of the hypostome has special slime-cells which lubricate any large portions of food, such as water-fleas, which enter it.

Movement. Hydra is *sessile* (Latin: sitting), spending most of its time in one spot; but it is capable of moving to another place. It does this usually by bending over until its tentacles touch the ground or other support, and then shifting its foot: after this it regains its erect position and, if necessary, repeats the operation. When touched the animal contracts suddenly to a size not much more than that of a pin-head. (See Plate IV.)

Symbiosis.

Although hydra is an animal, and therefore must obtain its food in the form of complex substances, it is often helped in the process by groups of little green plants (algæ) which live inside its body. These carry out photosynthesis, and the hydra absorbs the surplus food which they make, while the plants obtain shelter and suitable living conditions. The association is therefore beneficial to both organisms, and such an association is called *symbiosis* (Greek: living-together).

> INQUIRY 87. Observe with the low power of the microscope as many as possible of the above features in the living animal. Then examine prepared slides of the transverse section of hydra, showing cell structure, and longitudinal sections or whole mounts showing buds and sexual organs.

"As High as a Worm."

Few of us would like our physical or moral stature to be likened to that of a worm, which is generally considered a pretty low creature in every sense of the term. Yet, by comparison with the animals we have just considered, the worm is quite a noble being. It breathes the same air as we do: has a blood-circulatory system, a nervous system, and even a rudimentary brain. It is the first animal we have met in this chapter which can boast a head: and many of its habits would, in any other animal, be considered quite intelligent. It is an outstandingly clean animal in one sense at least: namely, that its skin produces a substance which kills any germs which are present—a process which, if extended to human beings, would relieve us of the need for washing our bodies. In spite of all this, it is traditional to speak disparagingly of the worm—as in the saying: "*Even* a worm will turn."

The Earthworm.

The earthworm is only one of a large group of animals known as the *Annelids* (Latin: *annulus*, a ring), whose bodies are made up of many ring-like segments or portions, most of which are very much alike. In the earthworm there are about one hundred and fifty segments distinguishable, from the outside, by grooves encircling the body, and separated from each other internally by partitions, rather like the watertight compartments of a ship's hull, but with the alimentary canal, nerves and main vessels running right through them (Plate VIII).

There is no hard skeleton, and as the worm is not aquatic there must be some means of supporting the body-wall. This is done partly by the muscles of the body-wall, and partly by the pressure of fluid in the cavities between the ectoderm and the alimentary canal. This fluid is produced by a layer of tissue which is not present in two-layered animals like hydra.

Mesoderm. This third layer of tissues, between the ectoderm and endoderm, is called *mesoderm* (Greek: middle layer), and is found in all animals which are more highly developed than the cœlenterates, sponges and similar simple creatures. From the mesoderm the reproductive and excretory organs are formed. It usually also gives rise to a true body-cavity, as distinct from the digestive cavity of the cœlenterates. This cavity is called the cœlom (Greek: hollow), and in the earthworm it is the cœlomic fluid which gives the animal whatever rigidity it has.

General Appearance. The earthworm is flesh-coloured, with a narrow pointed head whose shape assists it in burrowing. On its underside, protected by an overhanging flap, is the *mouth*. The skin is covered with thin cuticle, which in turn is protected by a thin layer of antiseptic slime, secreted on to it through pores.

The slime enables the animal to absorb dissolved oxygen through its skin.

On the underside of each segment are eight very short stiff *bristles*, called chætæ (Greek: hairs), which enable the animal to grip the surface over which it crawls. There are muscles attached to the chætæ, by which they can be withdrawn into the skin.

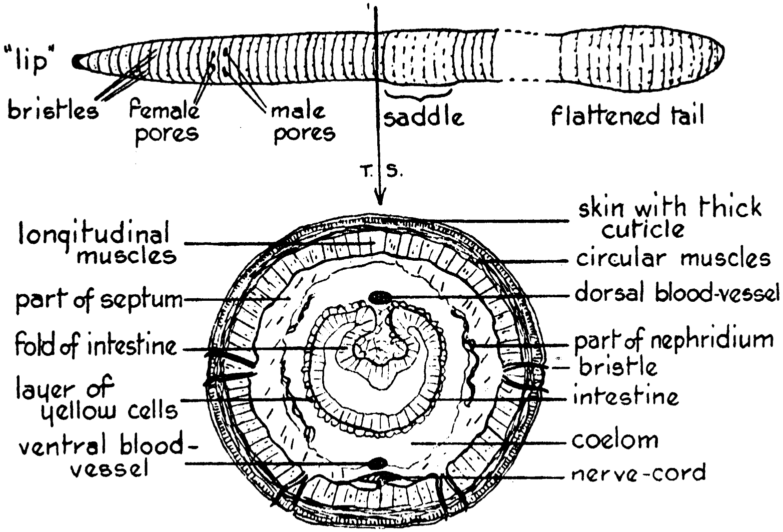

FIG. 91.—Earthworm, showing also a T.S. taken about the middle.

About a quarter of the way down the worm (segments 32–7) is a broad collar, the *clitellum* (Latin: saddle) which, as we shall see, is important in reproduction. The rear end of the worm is wider than the rest, and flattened.

Habits. The worm lives in a burrow which it makes by pushing the soil aside, or if it is hard, by eating its way through it, removing the humus as food and pushing the remains up to the surface as *worm-casts*. The worm plugs the opening of its burrow by drawing into it the narrow end of a leaf or a small stone.

The animal moves by alternately shortening and lengthening its body with the help of two sets of muscles, the outer set running round it, the inner set pointing along it (contrast hydra).

At the same time, it anchors each end of its body in turn by means of its chætæ. By co-ordinating these two operations it is able to move in either direction. It seldom leaves its burrow completely, preferring to explore with its "tail" safely wedged in the opening, from which one will find it surprisingly difficult to dislodge it.

> INQUIRY 88. Stroke the underside of a worm with the fingers to feel the chætæ. Then place the worm on a sheet of brown paper and listen to the scraping sound as it moves along. Place it on a sheet of glass and notice how, being unable to dig in its chætæ, it can only wriggle.

> INQUIRY 89. Keep worms in a wormery (a box with a glass side, and packed with layers of different-coloured soil. The glass should normally be covered with a cloth, as the worms avoid the light). Observe the habits and external features described above.

> INQUIRY 90. If you cannot keep a wormery, it is possible to test the reaction of worms to light as follows: Place a worm in a wide glass tube about two feet long, provided with two sleeves of black paper arranged to leave about three inches of clear space between them. It will be found that the worm avoids the clear space, even when the sleeves are moved to different parts of the tube.

Feeding and Excretion. The earthworm consumes large quantities of soil. In the process it necessarily swallows small stones and other hard material, which it grinds into powder in a muscular portion of its alimentary canal called the *gizzard*. The length of the intestine is limited in such a narrow animal by the length of the body (there is no room for coils), so its surface is increased by a deep internal fold along its dorsal surface (Fig. 91). The fold is filled with special *yellow cells* which appear to absorb waste matter and then break loose into the cœlom, from which they are collected, along with other waste matter, by a pair of coiled tubes with funnel-shaped ends, present in every segment except the first three and the last. These tubes, called *nephridia* (Greek: *nephros*, kidney), are the worm's *excretory organs*, and each leads to the exterior by a pore situated in the groove between segments.

The work of the worm in aerating, turning and levelling the soil was referred to on page 168.

Circulation. The earthworm has a system of blood-vessels, of which the most important are the *dorsal* and *ventral* vessels, and five pairs of connecting-vessels between them in segments 7–11. These connecting-vessels are muscular, and are called *hearts*. The dorsal vessel too is muscular, and pumps the blood towards the head. The hearts pass it to the ventral vessel, from which it is distributed by branches and capillaries all over the body, and finally returns to the dorsal vessels. The blood is red, but the hæmoglobin (page 143) is dissolved in the plasma and not carried in corpuscles. Lymph is also present.

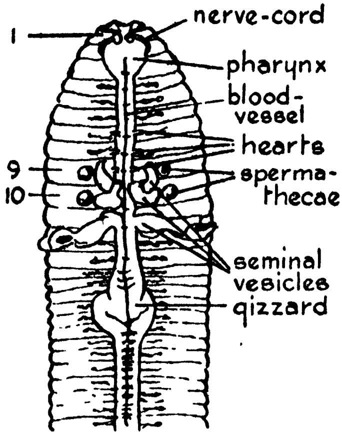

FIG. 92.—Dissection of front part of Earthworm.

Nervous System. At the front end, lying on top of the rather large pharynx, the worm has a pair of little knots of nervous tissue which can be considered as just the suggestion of a brain. From these *ganglia* (Greek: *ganglion*, knot), connecting threads pass round the pharynx to the ventral side, where they join at the beginning of a *ventral nerve-cord* which passes back throughout the length of the worm, giving off fibres to all parts of the body. It is important to notice that the nerve-cord is ventral, whereas in the vertebrates it is dorsal.

The earthworm has no special sense-organs, but is definitely irritable (page 222), showing marked preference for darkness, and recoiling quickly in response to vibrations of the ground. Its method of dealing with leaves and stones to protect its burrow suggests a sense of touch, and experiments show that it prefers some types of food to others.

Reproduction. Earthworms are *hermaphrodite* (Greek: Hermes and Aphrodite, a god and goddess): that is, each individual is both male and female, as in hydra. In spite of this, two individuals take part in the process of reproduction. Two pairs of testes, in segments 10 and 11, produce sperms which, after being stored for some time in sacs called seminal vesicles, are ready for transfer to another worm. The ovaries in segment 13 produce eggs which pass along oviducts on their way to the exterior.

When reproduction is to take place, two worms lie head-to-tail, with the clitellum of one opposite segments 9–11 of the other. Sperms from each worm escape from pores on segment 15 and pass along grooves outside the body to segments 9, 10 and 11 of the other worm, and into little storage-pockets called spermathecæ (Greek: sperm-case). The worms separate, and each liberates about fifteen eggs from pores on segment 14. The eggs pass back along grooves to the clitellum, which has meanwhile secreted an elastic collar. This collar now begins to move forward (in fact, the worm is wriggling out of it): and as it passes segments 9, 10 and 11, the sperm which was received from the other worm passes into it and fertilizes the eggs. As the collar passes off over the worm's head the ends close up, making a lemon-shaped *cocoon.* Inside this, as it lies in the soil, one of the fertilized eggs develops into a miniature worm. The others seldom develop and usually serve as food for the one which does.

Regeneration.

Because the segments of the worm are so much alike, any of them can, in an emergency, develop the structures and functions normally found in the others. If an earthworm is cut into pieces, each piece, given a reasonable chance, will grow into a complete worm. This useful property of *regeneration* becomes less and less prominent as we proceed to more highly developed animals, until in Man it is represented only by a few simple relics, such as the replacement of hair and finger-nails, and the healing of flesh-wounds. Its loss is part of the price which has to be paid for the benefits of specialization.

A Parasite—The Tapeworm.

Tapeworms live in the intestines of mammals such as the horse, dog and Man. We shall briefly review the life-history of the tapeworm which lives in Man. It is called Tænia solium (Greek: *tænia*, ribbon; Latin: *solium*, gritty).

Like all parasites, the tapeworm has periods in its life when its chances of survival are very slender. To counteract this, the adult tapeworm produces enormous numbers of fertilized eggs, so that although many thousands are lost, a few manage to complete the life-cycle and so the race is preserved.

The adult tapeworm is a flat ribbon-like animal, several feet long, which hangs in the intestine among the digested food. It is attached to the intestine wall by a group of hooks and suckers on its "head". Except for the "head" all its segments are alike, and consist almost entirely of reproductive organs.

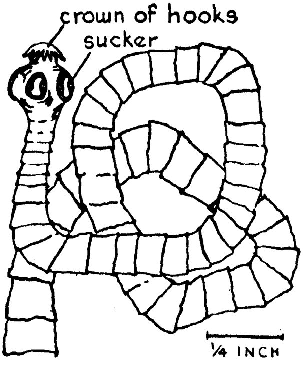

FIG. 93.—Tapeworm.

Since it is constantly bathed in digested food it absorbs this through its skin and has no alimentary system. Its surface is covered by a thick cuticle which protects it from the action of its host's digestive juices. There are no organs of sense or locomotion, as there would be of little use in its peculiar environment. A layer of muscle enables segments to double on each other to ensure cross-fertilization. It should be noted that the word "segment" here does not mean exactly the same as in the earthworm. A more correct term is *proglottid.*

The tapeworm is necessarily hermaphrodite, as there is little chance of two worms being in the same host. Cross-fertilization occurs, not between individuals, but between different proglottids of the same worm. When a proglottid becomes packed with fertilized eggs it breaks off and is carried out of the intestines with the waste products (fæces) of the host.

The fertilized egg cannot develop further unless it is swallowed by a pig, which is therefore known as the *secondary host.* Inside the pig, the embryo burrows into a muscle and becomes a *bladder-worm*—a small round bag with a miniature tapeworm-"head" tucked inside it. Pig's flesh infected with these bladder-worms is called *measly pork.*

If a human being eats measly pork which has not been well cooked, the bladder-worm will turn inside-out in his intestines, attach itself to the lining by its hooks and suckers, and develop into an adult tapeworm.

From the last two paragraphs it will be seen that, except for the time spent in its primary host (Man), the tapeworm's life is very precarious: and as a result, few people become infected, especially in civilized countries with hygienic farming and rigid meat-inspection. The infection is not fatal, resulting mainly in a slightly-reduced standard of general health.

Tænia is thus a typical internal parasite. It robs its host of food, and contributes nothing in return. Its structure is modified to enable it to survive in its strange environment (thick cuticle, means of attachment, prolific reproduction). It is also modified in a negative way to avoid wasting vital energy on unnecessary structures and functions, by dispensing with respiratory, digestive and sensory organs. It does not kill its host, as that would be like killing the goose that laid the golden eggs.

In general, its simple structure is a sign, not that it is a very primitive animal, but that it is degenerate and highly specialized. It is a fine example of reaction to environment (page 2); but whether it has reached its present condition by a slow process of modification through the ages, or has always been ideally suited to its environment is a matter for speculation (page 284).

QUESTIONS

SECTION A.

1. Describe with the aid of diagrams, the structure and functions of amœba.
2. What evidence would you give to prove that amœba is (*a*) an organism, (*b*) an animal?
3. Compare amœba and hydra under the headings of (*a*) General Structure, (*b*) Methods of Food-Capture and Digestion.
4. Draw and explain the action of a nematocyst (stinging-cell).
5. What is the difference between sexual and asexual reproduction? Describe the sexual reproduction of hydra, and state what advantages it has over reproduction by budding.
6. Describe the appearance and habits of the earthworm.

7. Describe the process of reproduction in the earthworm.
8. What are the characteristic features of an internal animal parasite?

SECTION B.

1. "Amœba and Lumbricus (earthworm) are equally suited to their environment." Discuss this statement.
2. Using hydra and the earthworm as examples, show how increased specialization of tissues brings increased command over the environment.
3. Write a short essay on the effects of earthworms in the soil.
4. State, giving reasons, which of the two methods of reproduction in amœba most nearly resembles sexual reproduction, and point out how it differs from true sexual reproduction.

CHAPTER XV

PECULIAR PLANTS

ONE of the biggest cells in the plant kingdom belongs to one of the smallest plants—*Spirogyra*. This plant is a member of the group of very primitive plants called *Algæ*, and consists simply of a thread of cylindrical cells joined by their ends. It is easily obtained in handfuls from the surface of a stagnant pool, or the sides of a slow-flowing stream. It has no means of attachment, so unless it becomes entangled with other plants it floats freely. It can be distinguished from other types of floating plant by its slimy feel; but do not let this disturb you. Most living things with a slimy feel are really quite clean, or even antiseptic, as in the case of the earthworm and the frog, whose slimy coatings protect them from the bacteria which otherwise would soon make short work of them.

> INQUIRY 91. Collect a small amount of Spirogyra, with some water from same place. Take a few threads of the plant and tease them apart with needles in a petri-dish: then transfer a wisp of them to a slide. Tease them out again on the slide in a drop of water and examine with the low power. The diagram (page 199) shows the appearance you will see.

Each filament (thread) seems to have a spiral green band running along it; but closer inspection shows that this cannot be continuous, as there are cross-walls at frequent intervals. These cross-walls mark the ends of the cells, and one cell should now be examined with high power.

> Try to see that the end-walls are double. In fact, each cell has its own end-walls, so that in a sense spirogyra could be described as a colony of unicellular plants joined by their ends. Sometimes the division between the end-walls is very difficult to see.

> Turn the fine adjustment up and down a little to satisfy yourself that the cell really is cylindrical, then adjust it to give a good view of the widest part—the diameter.

Each cell is almost a millimetre long and about a quarter of a millimetre in diameter. The walls are of cellulose, and the spiral green band (or bands—the number varies) is a large ribbon-shaped chloroplast embedded in the protoplasm which lines the cell-walls. At fairly regular intervals along the centre of the chloroplast are bright specks. These are called pyrenoids (Greek: resembling fruit-stones). They are centres of starch-formation, and if a cell is crushed and treated with weak iodine solution, the presence of starch round the pyrenoid will be shown by the appearance of a blue colour.

In the centre of the cell, suspended from the lining by threads of protoplasm, is a large nucleus. The remainder of the cell is a large vacuole filled with cell-sap (Fig. 93).

Spirogyra, being an aquatic (water-living) plant, obtains its oxygen in solution, and the carbon dioxide which it gives off in breathing also dissolves in the water. Its metabolism is the same as in the higher plants, except that its simple structure dispenses with the need for roots, conducting tissues, and stomata. All the substances needed for the process are dissolved in the surrounding water. Since, therefore, it carries out photosynthesis, there is no doubt of its identity as a plant.

Asexual reproduction. The normal reproduction in this plant is by the simple process of *fission* (Latin: splitting). When a cell has grown to full size, the nucleus divides into two identical portions, and these move apart. New cross-walls appear between them, growing inwards from the rim of the cell, and eventually close in completely, to divide the original cell into two complete cells. Each of these then begins to grow, and as this may happen all along a filament, its length continually increases. After a time the filament breaks up into sections (fragmentation), and these may be dispersed by currents or by animals brushing against them.

Sexual reproduction. When conditions are unfavourable for the normal life of the plant—due to the drying-up of the pond, or the loss of oxygen and carbon dioxide from the water—a special type of reproduction takes place.

Two threads which are lying close together take part in the process, which is called *Conjugation*, and is illustrated in Fig. 94. Some cells develop bulges on the side nearest the other filament, and corresponding bulges arise in that filament. The sections of the cell-walls which are thus brought into contact break down, forming a connecting-tube between the two filaments. Meanwhile, the contents of the cells involved have been rolling up into compact bodies, and one of these now squeezes its way along the tube into the other cell, where it fuses with the contents. The resulting body then secretes a thick protective coating, inside which it can withstand even the complete drying-up of the pond.

Soon the original cell-wall gets broken and the resting-body, which is called a *zygospore*, falls to the bottom of the pond. If the pond dries up, the zygospore may be blown away with the dust, but as soon as it reaches a situation where Spirogyra can flourish, it splits open and a new filament grows out of it. The first cell of this filament is colourless and sticky, and anchors the tiny plant until it becomes strong enough to face the conditions at the surface of the pond. Then the colourless cell withers away, and the filament floats up to its new home.

The process just described is one of the simplest known cases of sexual reproduction. In fact, it is so simple that many people think it is not true sexual reproduction, and that is why it is called conjugation; but it has the main features of the sexual process, so it is worth while to review them and see how far spirogyra carries them out.

(*i*) The process usually, though not always, involves two individuals.

(*ii*) Only part of each individual takes part in the process. (If we consider each cell of spirogyra as an individual it does not obey this condition.)

(*iii*) The reproductive part (gamete) of one individual, the male, moves towards and fuses with the female gamete.

(*iv*) The male gamete is smaller and much more active than the female gamete, which usually contains stored food. (Here again spirogyra fails to fulfil the conditions.)

(*v*) The body resulting from the fusion of the gametes is called

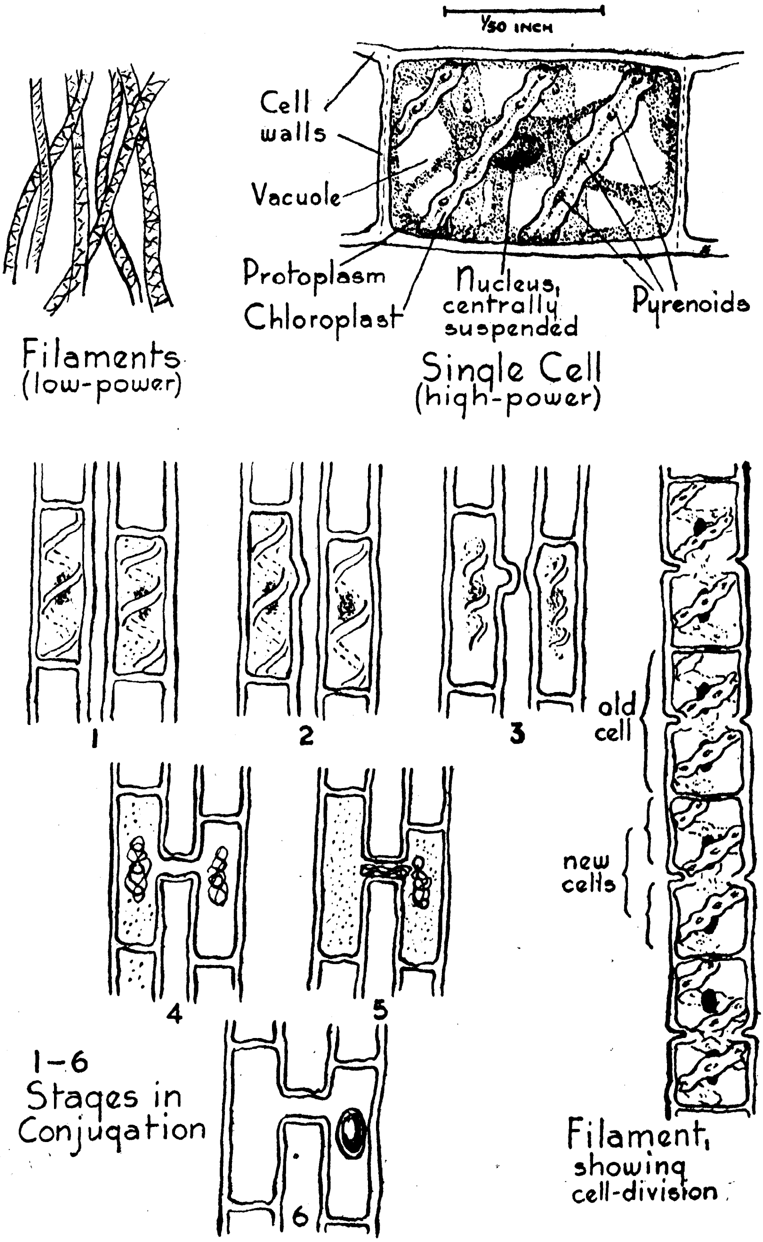

FIG. 94.—Spirogyra.

a *zygote.* (In spirogyra it is called a zygospore, just in case it is ever proved that the process is not true sexual reproduction.)

If you have read Chapter XIV, you will now see that sexual reproduction in plants is essentially similar to that of animals. This and other aspects of reproduction are referred to again in Chapters XX, XXI and XXII.

The cell of spirogyra is sometimes described, even in examination syllabuses, as a *typical* plant-cell. This statement should be treated with caution, since the size, shape and chloroplast, at least, are far from typical: and few other plants studied in an elementary course are aquatic.

Other Algæ.

The group of plants to which spirogyra belongs contains many other common and interesting plants. One of them is *Pleurococcus*, which is seen as a green coating on the trunks of trees, damp garden walls and fences. If you are a scout or guide and study woodcraft, you will know that the green side of a tree-trunk is the side facing the prevailing wind. This is because the wind drives the rain against this side of the tree, and pleurococcus, having no roots, can only absorb gases and salts when it is in direct contact with a film of moisture, containing minute quantities of mineral salts which have dissolved into it from the dust and debris on the surface of the tree.

Pleurococcus is a unicellular plant, the cells when single being round; but when a cell reproduces by fission the daughter-cells often remain attached to each other and eventually reproduce by fission themselves, thus forming a cluster of four cells in the shape of a hot cross bun. The name "Pleurococcus" means "several round bodies". The appearance of the plant is clear from Fig. 95. The cells are much smaller than those of spirogyra.

The two algæ already described belong to the green algæ, but there are also the brown algæ, including most of the common seaweeds, such as the bladder-wrack (*Fucus*), and there are signs that such organisms have many useful qualities which were overlooked until the needs of war turned the attention of scientists to them. In the 1939–45 war, seaweeds provided food, plastic materials similar to cellophane, and textile fabrics which combine the delicate texture found in silk with the heat-preserving qualities of flannel. The main substance in all these commodities is a chemical called *algin.*

Plants Which Dine Out.

Although most plants make their own food from simple chemicals, there are some which adopt the easier course of living on food manufactured by other organisms. There are two great groups of these: the saprophytes and the parasites.

Saprophytes (Greek: rotten plants) live on the remains of dead organisms.

Parasites (Greek: living alongside their food) live on or in living organisms and derive all their food from them.

Most of the saprophytes and parasites are included in the large and varied group of plants called *Fungi*, and as most of the fungi are saprophytes we shall begin by examining some of these fascinating plants.

Mucor.

INQUIRY 92. Sprinkle a few drops of water, preferably freshly distilled, on a piece of bread about two inches square; place it on a saucer which has just been washed in very hot water and allowed to cool, and cover with a similar saucer or petri-dish to reduce evaporation. Leave for a week in a warm place, and then examine the bread. It will be found to have a rather unsavoury smell and patches of furry growth will be seen on it, probably in several colours.

These patches are the reproductive bodies of several saprophytic plants known as *moulds*, and are the outward signs of flourishing plants within the bread. How did they get there? Bread is made from flour which is a plant-product but has had the living material removed. It is baked, and therefore most unlikely to contain living organisms. The containing vessels and the added water were not likely to harbour living organisms after their heat-treatment, so the plants must have reached the bread through the air; but the air surrounding the bread was no different from any normal atmosphere, and there were no signs of plants in it when we covered the bread.

Thus the plants must be present, in some form, in any normal sample of air, and must be invisible. In fact, the bread has become infected with microscopic *spores*, which are always present in ordinary air and will grow into mould-plants in suitable conditions. These are warmth, moisture, and a supply of food, all of which we provided in the Inquiry.

One of the moulds on your piece of bread will almost certainly be *Mucor*, or its near relative Rhizopus, which is so like it that we need not worry about the differences. These are commonly known as *Pin-mould.* The diagram shows how it would look if you could take the bread away from it.

The plant consists mainly of a felt of very slender colourless threads which grow out in all directions through the bread. These, because of their size and lack of colour, are not seen by the naked eye against the white or nearly white background, even if the bread is cut open. Each filament is called a *hypha* (Greek: *hyphe*, spider's web), and its nuclei are not separated by cross-walls.

This arrangement is sometimes described as multi-nucleate, and sometimes as non-cellular, but it is safer to avoid confusion by using the technical term *cœnocytic*, which means "having many nuclei without any cross-walls", and so cannot be misunderstood. The hypha of mucor does not contain any cellulose (though there are moulds which do), and since it does not carry out photosynthesis it neither needs nor possesses chlorophyll. This may lead you to ask: "Why, then, do we know it is a plant, and not an animal?" The answer to this is not simple, but we may say that the organism shows so many close similarities with others which are undoubtedly plants that there is no doubt of its identity. The mass of hyphæ in mucor and in all fungi is called a *mycelium.*

Reproduction. At the surface of the bread (or other substance on which it grows, such as jam, beetroot, or animal manure) there are much thicker hyphæ which stand erect into the air and have round black heads on them, making them look like pins—hence the common name. Each of these heads is crammed with spores, and the end of the hypha projects into the head and swells up gradually, like a rubber balloon, as water is forced into it through the stalk. The swollen portion is called the *columella*, and the pressure of water in it at last becomes so great that the

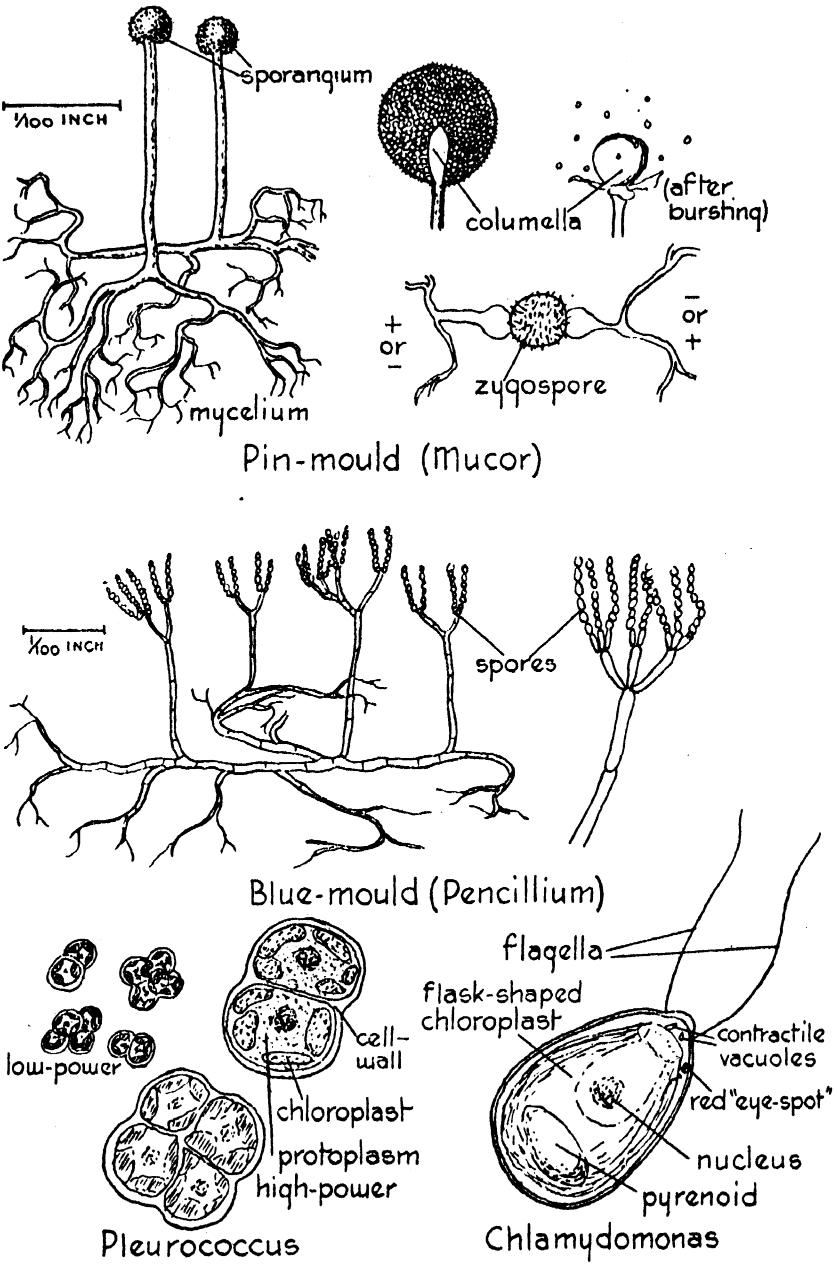

FIG. 95.—Some peculiar plants.

brittle black skin of the head is shattered into fragments and the spores are shot out violently into the air, where they are carried around by draughts until they find a suitable place to settle. A new hypha grows out of the spore and the life-story begins again. The diagram shows enlarged views of the head in section, and of the hypha after the head has burst, with the columella and the remains of the black skin.

Sometimes, if two different mycelia are close together, the ends of two of their hyphæ may touch, and then cross-walls form near the ends. The two portions thus cut off fuse together and form a black spiky body called a zygospore (compare spirogyra). The use of this term shows that this process is believed to be a primitive kind of sexual reproduction, and the two end-cells which fuse together are therefore called gametes. The belief is strengthened by the fact that fusion cannot take place between just any two mycelia but only between certain types of mycelium. The difference between these mycelia has not yet been discovered—it is impossible to see any difference, even under the microscope, so they are described as plus and minus strains, not as male and female.

Penicillium.

Another mould which you may find on the piece of bread is the common *blue-mould* or *green-mould* which is also often seen on old leather. This is *Penicillium*, one particular species of which (P. notatum) has become very important as the source of the drug penicillin. Other moulds are being studied to see if they can provide equally good or better drugs, and there are good prospects of success, as in the case of streptomycin, from streptomyces.

Other Fungi.

Moulds have been used—often unknowingly—for centuries in the ripening of cheese and the manufacture of wine. If you keep an aquarium and have had the ill-luck to have one of the fish die and float unnoticed for some hours in the water, you may have seen a white furry mass, like a halo, all round its body. This is a mould called Saprolegnia, and if not removed and the tank disinfected it will quickly infect other occupants.

Few moulds are parasitic, and one which used to be much commoner than it is now, at least in this country, is the cause of a skin-disease—*ringworm*. The round red patches which are the signs of this disease are caused by the mycelium which spreads radially from a spot under the skin-surface.

Some well-known examples of larger fungi are the mushrooms and toadstools, puff-balls, stink-horns and truffles, and the bracket-fungi which are often seen on the trunks of trees, and play a big part in breaking them down into humus. Many crop diseases which have caused disastrous famines are caused by microscopic fungi such as the potato-blight, rust of wheat, and pythium, which causes damping-off of seedlings.

Yeast.

We cannot leave the fungi without considering perhaps the most remarkable of them all, as well as one of the most useful, known as *Yeast*. This plant has reduced the chemistry of its life-processes to such a fine art that it does not even need a mycelium. It consists simply of oval cells, from which new ones are continually being budded off, so that in suitable conditions, namely a warm sugary solution, the number of cells can increase at an astonishing rate. It normally breathes-in oxygen and gives off carbon dioxide, a process of which advantage is taken in bread-making. Barm, which is simply pressed yeast-cells, is mixed with the dough and put in a warm place. The yeast produces carbon dioxide, which blows holes in the dough, making it "rise", in which condition it is fixed by baking, so that the bread is full of small holes, making it more palatable and easier to digest.

When there is not enough oxygen available for respiration, this amazing plant does not, as we should, give up the ghost. Instead, it switches over to anaerobic respiration (page 63), breaking down the sugar to alcohol and carbon dioxide, and so obtaining the energy it requires. Now this reaction can only be carried out on a monosaccharide (page 66) such as grape-sugar, $C_6H_{12}O_6$; if the yeast is floating in cane-sugar, which is a disaccharide, $C_{12}H_{22}O_{11}$, it first converts it to sugar of the required formula as follows:

$$\underset{\text{cane-sugar}}{C_{12}H_{22}O_{11}} + \underset{\text{water}}{H_2O} \longrightarrow \underset{\substack{\text{grape-sugar}\\ \text{(glucose)}}}{C_6H_{12}O_6} + \underset{\substack{\text{fruit-sugar}\\ \text{(fructose)}}}{C_6H_{12}O_6}$$

These reactions are carried out, not directly by the plant itself, but by means of substances which it produces, called *enzymes* (Greek: in-yeast), a class of substances which may be described as organic catalysts. Animal enzymes have already been described in Chapter IX.

The conversion of sugar into alcohol by yeast is called *fermentation*, and is made use of in the manufacture of beer and whisky, and the large quantities of yeast which result are compressed and sold to bakeries, or to the public as patent medicines in the form of yeast tablets. Alcohol is also used to some extent as a motor spirit and as a general-purpose fuel.

Our final example of a fungus is another example of symbiosis (page 187). When we were describing the root systems of plants it may have occurred to you that an enormous tree could scarcely have enough root-hairs at the tips of its roots to absorb the many gallons of water which pass up its trunk.

This is so, and many trees, notably the beech and birch, depend almost entirely for their water-supply on the activity of a fungus which covers their roots. This fungus is called a *mycorrhiza*, and gives water to the plant in exchange for food.

Bacteria.

Though most saprophytic and parasitic plants which are known to botanists, and all the examples of them which have been described in this chapter, are fungi, there are examples among other plant-groups. The *Bacteria* are plants whose mode of living is still much of a mystery, but among those which have been closely studied, many are saprophytes or parasites. They are so small that they passed unnoticed until the introduction of powerful microscopes.

The word bacterium means "little stick", and this describes the appearance of many of them. They are unicellular, and apparently so simple in structure that there does not appear to be even a nucleus, unless it is scattered among the rest of the protoplasm in the cell. Their size seldom exceeds one ten-thousandth of an inch, and their shape may be rod-like (bacilli), round (cocci) or coiled (spirilla). Some of them have tufts of cilia by which they swim in liquids, but most of them are unable to move of their own accord. They reproduce by simple fission at frequent intervals, so that in suitable conditions countless millions may be produced in a day. This accounts for the souring of milk in hot weather, for all the processes we know as putrefaction and decay, and for a large number of the diseases of animals and Man. On the other hand, the vast majority of bacteria are harmless, and many perform useful work. Their activities are discussed in the next chapter.

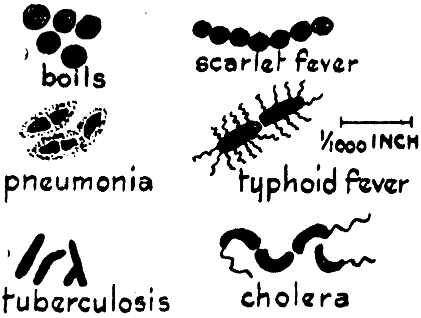

FIG. 96.—Bacteria.

INQUIRY 93. Sterilize three petri-dishes and covers by steam treatment, and run into each dish a layer of sterile nutrient agar (made by adding beef-extract to agar-solution and heating the flask, plugged by cotton-wool, for a full school day on a water-bath). Cover one of the dishes at once as a control, lay the tips of the fingers lightly on the setting agar in the second dish before covering, and expose the third to the atmosphere for about fifteen minutes after it sets, preferably where flies may walk on it.

Now set the covered dishes in a warm part of the room, and examine (without uncovering) at intervals for a few hours.

Soon, finger-prints will appear in one dish, traced by colonies of moulds and bacteria which have grown from the spores and germs on the fingers. The bacterial colonies will be seen as whitish specks. The dish which was exposed to the air will show similar patches, and if a fly did walk on the jelly its footprints will be marked by patches of mould and bacteria.

Flowering Parasites.

There are not many parasites among the flowering plants, at least in Britain. Two of the commonest are the dodder and the broomrapes, and it is worth while to investigate them.

Dodder. The commonest species of this plant is found on heather-plants and whin-bushes, especially in Surrey. There are no leaves, and at first sight the plant seems to consist only of thin thread-like red stems twined round the stem of the host-plant, and little clusters of rather pretty pink flowers. Closer inspection shows that the stem of the dodder is attached to the host by small *suckers*. These may be considered as adventitious roots, and are the plant's only means of obtaining nourishment, which it absorbs from the tissues of its host.

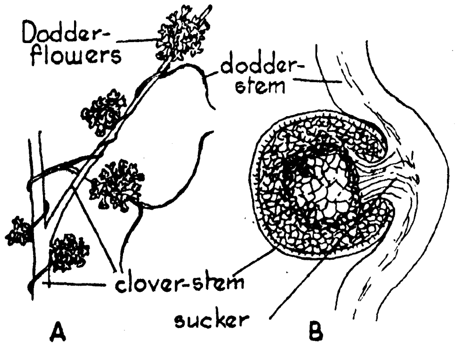

FIG. 97.
A.—Dodder on Clover.
B.—T.S. showing how Dodder is attached.

Fig. 97 shows the general appearance and the way in which the suckers invade the host-stem. The flowers are like miniature copies of the bindweed (convolvulus) to which the dodder is related. There is another species of dodder which attacks clover-plants and has yellow stems.

Broomrapes. These plants are bigger than the dodders and bear flowers which remind one of the foxglove, to which they are related; but the broomrape flowers are smaller and stand erect instead of drooping. It is not at first obvious that the plant is a parasite, because its attachment to its host is below-ground—it is a root parasite. Like the dodders, the broomrapes do not contain chlorophyll, having no use for it.

Mistletoe.

The well-known Christmas decoration, though pleasant in appearance and a great social asset, has a skeleton in its cupboard—it is a *semi-parasite*. This plant robs its host (apple, elm, willow, oak and many other trees), not of organic food, but of water and salts. The leaves of the mistletoe are green and carry out photosynthesis, but the water and mineral salts which are also necesary are obtained by a root which penetrates the trunk of the host.

The seeds of the plant are sticky, and birds (especially the thrush), which eat the berries, rub their beaks on the tree-trunks to rid them of the seeds, which are thus attached in just the right place for their development. An interesting fact is that the root of the mistletoe is not geotropic (see Chapter XVIII), that is, it does not move downwards in its growth, as do most roots. Instead, it is negatively phototropic, growing away from light. This course naturally directs it into the interior of the tree-trunk on which it grows.

Lichens.

One of the most remarkable cases of association between organisms is that found in the lichens. A lichen consists of a green alga in close association with a fungus. They contribute to each other's metabolism, and while in some cases the alga could exist alone this is never true of the fungus. Here is a really good example of symbiosis.

QUESTIONS

SECTION A.

1. Describe, with the aid of diagrams, the structure and reproduction of spirogyra.
2. Write short notes on each of the following, pyrenoid, fission, gamete, zygospore, using spirogyra as an example in each case.
3. Why is it thought that the conjugation of spirogyra may not be a true case of sexual reproduction?
4. What is a parasite? Show how the structure of mucor is specially adapted to enable it to live as a parasite.
5. Describe, with diagrams, the asexual reproduction of mucor.
6. What is the difference between the aerobic and anaerobic respiration found in the yeast plant?
7. State why, in your opinion, the bacteria are classified as plants.
8. Describe the appearance and peculiarities of structure of either a dodder or a broomrape.

SECTION B.

1. State the evidence for considering spirogyra as (*a*) unicellular, and (*b*) multi-cellular.
2. Compare sexual and asexual reproduction, using spirogyra as example.
3. Write a comparative account of the reproductive processes of spirogyra and yeast.
4. Write a short essay on the importance of bacteria.

CHAPTER XVI

FRIEND OR FOE ?

MAN'S relation with other organisms is seldom one of neutrality: and when it is so it is usually armed neutrality—that is, we leave many organisms alone unless and until they obstruct our plans, and then we take aggressive action. This power over our environment, which makes us call ourselves the "lords of creation", is not maintained without a great struggle against heavy odds, and it is only the mental superiority of mankind which keeps us on the winning side. Physically, Man is in many ways at a great disadvantage when matched against other organisms.

From what you have just read you should see that no book would be big enough to list all the friends and foes of Man among the organisms which surround us. In this chapter, therefore, we can only review a few examples.

Friends Among the Plants.

Most of the plants useful to use are those which provide *food*, *clothing* and *shelter*. The majority of them are flowering plants, and you should have no trouble in finding scores of examples.

> INQUIRY 94. Make lists of ten flowering plants in each case which contribute to our welfare under the headings: Food; Clothing; Shelter. Compare your lists with those of other students and observe the great variety of such plants.
>
> INQUIRY 95. Repeat the previous Inquiry, confining your list to non-flowering plants. This time it is not so easy.

Unseen Friends. There are many useful, and indeed indispensable, plants among the *moulds* and *bacteria*, which carry out, unseen, tasks which make life easier for us. Think what would happen if all the dead plants and animals just lay around and went on piling up year after year. There would soon be no room on the ground for the living. This is prevented by the activity of the scavenging and putrefying bacteria, which reduce the bodies of dead organisms to simple chemicals which are released as gases or help to form humus, and are used again by other plants and animals.

> INQUIRY 96. If you have a garden, make a small compost heap, using Fertosan, and following the instructions in the packet. Fertosan is a preparation of putrefying bacteria which have been specially treated to allow them to be stored in packets. Note how rapidly the plant-remains decompose. Set up a control without any Fertosan.

Bacteria and moulds also carry out *fermentation* (page 206) which provides us with alcohol. Whether such organisms are friend or foe is a matter of opinion.

In recent years moulds have been used as sources of valuable *drugs* such as penicillin and streptomycin.

Many other examples of useful plants are referred to in other chapters.

Harmful Plants.

Plants may be useful and harmful at the same time: thus the stem of the rhubarb plant is a food but its leaves are poisonous. Similarly, many plants provide valuable *drugs* which, taken in large doses, may prove fatal. Examples are foxglove (digitalin), opium poppy (morphia, laudanum, opium) and deadly nightshade (belladonna, atropin).

Some plants which outwardly appear very similar may have very different effects on the human system, as in the case of mushrooms and toadstools.

The putrefying bacteria and moulds are harmful when they attack useful substances such as food and clothing, as in the souring of milk, and the mildew of clothes.

Of the exclusively harmful plants, *parasitic fungi* cause great losses in food-production, and sometimes, by causing famines, have changed the course of history. Examples of such destructive organisms are the potato-blight, rust of wheat, and the damping-off fungus (pythium) which destroys seedlings.

Parasitic flowering plants are less troublesome but some twining-plants, such as convolvulus (greater bindweed), though not strictly parasitic, strangle valuable crop-plants.

The *bacteria* include large numbers of very harmful species which are responsible for a high proportion of the most dangerous diseases of Man and domestic animals. The well-known fevers such as measles, chicken-pox, scarlet fever, cholera, typhoid, diphtheria and pneumonia are all caused by bacteria, as is the terrible disease, tuberculosis, which is so prevalent in civilized countries, where most of the people live in towns. A great step was taken in the fight against bacteria when Lord Lister (1827–1912) introduced the first antiseptic, carbolic acid, to be used in surgical operations.

Viruses. There is a group of organisms, even smaller than the bacteria, about whose life-history little is known for certain. Even their name is significantly vague, meaning simply "poisons". Some of these organisms are only the size of a single molecule, and have even been found to crystallize. The *common cold* is caused by a virus.

Weeds. Most plants, especially flowering plants, may be either desirable or just a nuisance, according to the place in which they grow. In general, it may be said that any plant, growing in a place where it is at the time a nuisance is a weed. Thus lawn-seed scattered on a lawn produces valuable lawn-grass, but the same seeds, falling by mistake on an ornamental flower-bed, would produce weeds. The plant is the same in both cases, but in one case its position makes it a weed. Similarly, if expensive flower-seeds intended for the border fell on the lawn, the plants they produced would be weeds because they were out of place.

Some plants seem never to grow anywhere but out of place, and it is these of which people usually think when they hear the term "weed". Examples are chickweed and groundsel, which are common garden nuisances, and charlock, which is often said to "follow the plough"—that is, it springs up in newly-ploughed earth, because the seeds were there already, and the ploughing introduces just the right conditions of moisture, air, etc., for germination.

Animal Friends of Man.

First among the animal friends of Man, the *domestic animals* spring to the mind: and it is worth while to remember that in various parts of the world, some of the most "unlikely" animals are domesticated, the list ranging from rabbits to elephants, and from canaries to ostriches.

Next, one naturally thinks of *livestock* used for food and traction. It may seem strange to class an animal as a friend and then kill and eat it; but such is the case, and most livestock have at least an easier life than they would in the wild state.

Many animals become our friends only after their death. Examples are foxes, tigers, snakes, crocodiles, and others whose skins are ornamental and useful. Most of the *regularly-hunted animals* fall into this class, from moles to whales, because they contain food or other useful materials. In this connection we must remember the fresh-water and marine *fish*, which provide food and livelihood for millions of people all over the world.

All the animals mentioned so far in this section have been vertebrates, and in general it may be said the friendly or useful animals are vertebrates, while the invertebrates are more likely to be harmful. There are, of course, many exceptions on both sides. Useful invertebrate animals include the silk-worm and honey-bee among the insects, shell-fish, sponges and coral from the sea, and the earthworm on land. Animals whose value you may not have suspected include scale-insects (related to green-fly) which produce shellac for varnish, cochineal insects from which we get the colouring for pink icing on cakes, and spiders which provide fine silk threads for use in the eyepieces of delicate optical instruments.

Very many animals benefit Man indirectly, by preying on other organisms, and so helping to maintain the balance of nature and saving us from being swamped by plagues of one or other kind of organism. More will be said about this at the end of this chapter.

Dangerous Animals.

As already suggested, the most dangerous animals are invertebrates. More people have owed their deaths to microscopic animals than to all the lions, sharks, snakes and crocodiles in existence. In the Indian peninsula alone, in a normal year, two million people die from malaria. In an epidemic, the local death-rate from malaria may be increased twenty to thirty times.

Parasites.

We shall consider first, some animals which attack Man directly, living on or in his body. Examples of *external parasites* are fleas, lice, and bugs. All these have specially-shaped mouth-parts which allow them to pierce the skin and suck blood, or to inflict poisonous bites. Only certain species of each type concern themselves with Man. Other species prey on other animals. The main danger attending these external parasites of Man is not their blood-sucking activities, which result mainly in minor irritation, but in the other organisms which they carry round with them, and introduce into the human body. Thus, lice carry the germs of typhus fever; the tsetse-fly transmits unicellular animals which cause sleeping sickness; and one species of mosquito transmits a unicellular animal which causes malaria.

Examples of *internal parasites* are plasmodium, the one-celled animal which enters the blood through the piercing tongue of a mosquito and causes malaria: and the *tapeworm*, which has been described in Chapter XIV (page 192).

An interesting case of disease-transmission is that of bubonic plague. This is a disease which attacks rats and other animals as well as Man. It cannot pass directly from a rat to a man; but if a man is bitten by a flea which has previously bitten a plague-infected rat the disease is passed on to the man. This explains why strict precautions are taken at ports to prevent rats from entering the country from ships which have been in countries where the disease is common.

Destructive Animals.

Apart from the transmission of disease, animals can be harmful by destroying food and other valuable material. Rats annually destroy millions of pounds' worth of materials in this country alone. Rabbits in Australia are equally destructive (page 108).

Locusts in the Middle East and in China cause famines by consuming crops which have been grown to support vast populations: and they do not stop at eating the growing crops, but also destroy all the textiles they can find, so that a household in the path of their advance may be stripped in a few hours of all clothing and soft furnishings such as curtains, upholstery and bedding.

Every gardener knows the damage that is done by slugs, leather-jackets, carrot-fly, and a host of other small animals. The Colorado beetle has achieved the distinction of having its picture circulated to police stations throughout the country as an "honorary member" of the rogues' gallery. This is because of its devastating effect on potato-crops. People are asked to take or send for identification any beetle they think may be a Colorado beetle so that measures may be taken promptly to arrest its spread.

Control of Organisms.

The search for methods of controlling organisms is perhaps the most fascinating part of the study of biology, and certainly affords some very interesting stories. The histories of farming, fishery, horticulture and medicine are full of such stories; and many biological terms which have arisen during the search—pasteurization, vaccination, antisepsis, immunization, incubation—have passed into common use.

The control of desirable organisms is so vast a topic that we cannot hope to deal adequately with it, but must content ourselves with the observation that modern crops and livestock are an outstanding tribute to its success (page 280).

The control of undesirable organisms has advanced from the stalking of wild animals by cave-men with stone weapons, to the transportation by air of enough anti-cholera serum to inoculate the entire population of Egypt, in the cholera epidemic of 1947. Modern control takes many forms, and we shall briefly consider a few of them.

Before any method of control can be confidently applied, the life-history of the organism to be controlled must be known to the last detail, and this often involves many years of patient observation, and sometimes demands great sacrifices, even of life, on the part of the investigators. The life-stories of Robert Koch, Louis Pasteur, Sir Patrick Manson and Sir Ronald Ross, among scores of others, contain episodes as thrilling as any to be found in the lives of famous soldiers or explorers.

Robert Koch discovered the bacillus causing tuberculosis, and invented the methods of "culturing" bacteria which are still in use in laboratories all over the world. He died in 1910.

Louis Pasteur (1822–96) was not only the greatest biologist of his time but one of the greatest of all scientists. His experiments are perfect examples of true scientific method, involving painstaking observation and the use of control experiments to ensure that any results observed can be traced to their true causes, and proper allowance made for the effect of other factors which are not being investigated in the experiment, but which may influence its results.

His work on diseases of grape-vines saved the French wine-industry from extinction. His cure of anthrax in sheep saved thousands of farmers from ruin. He tracked down a disease of silk-worms which threatened the staple industry of large areas of the south of France. His whole life is an illustration of the fact that scientific investigation, carried out from the right motives, namely a love of knowledge and a search for truth, cannot fail to benefit the investigator and mankind in general; though the benefits are not always so quickly realized as they were in his case.

Pasteur's demonstration of the value of asepsis (complete exclusion of germs) in surgery, and his discovery of pasteurization of milk (see below), have probably saved more lives than were lost in the two great wars of this century.

Pasteurization. In the eighteenth century an Italian priest, Lazaro Spallanzani (1729–99) showed that no organisms developed in foods which had been boiled and made air-tight: and that the foods consequently did not go bad. Pasteur developed this work further and used it to disprove the theory of spontaneous generation, which had been widely held up to that time, and which claimed that life did in fact appear in substances which had previously contained no life. The belief was due to faulty observation of such things as the development of maggots in refuse. The maggots come from eggs which are deposited in the refuse by flies. This process passed unnoticed by casual observers, who thought the maggots were produced by the refuse itself. When this point had been cleared up it still remained true that even if all visible living things were excluded, organisms continued to appear. Pasteur's painstaking experiments proved conclusively that even in such cases the organisms were introduced, already living, from the microscopic dust in the atmosphere. This knowledge has since led to the world-wide establishment of food-preservation by canning, followed by steam-heating.

It was soon found, however, that such drastic methods of preserving food seriously reduced the quality of some of them, particularly milk. It is now known that the main cause of this is the destruction of the vitamins, but in Pasteur's time these had not been discovered. Pasteur carried out many long experiments on the germs responsible for tuberculosis and souring, and he discovered that by heating the milk to a temperature of about 140°F. for half an hour and then cooling it quickly, most of the dangerous germs are killed without seriously affecting the value of the milk. This process is called pasteurization, and it is likely that before long in this country a law will be passed to make it compulsory to pasteurize all milk unless it has been tested and proved free from tuberculosis germs.

Patrick Manson (1844–1922), discovered at Amoy, in India, that the disease, elephantiasis, is transmitted by a mosquito, and he suggested that malaria might be transmitted in the same way.

Sir Ronald Ross, who worked with him, proved in 1898 that this was so, and as a result it became possible, by destroying the mosquitoes or preventing them from biting humans, to control the disease. This made it possible for large areas of the world to be developed, which had previously been uninhabitable. Once the organism responsible for a disease has been identified, control of the disease is achieved by either destroying or excluding the organism and its carriers. In the case of the mosquito, oil is spread on the water where they breed, and this suffocates the larvæ. The adults are dealt with by the use of mosquito netting, which keeps them away from sleeping persons, and by special ointments which discourage them from piercing the skin.

Drugs developed during the 1939–45 war have made it possible to kill the plasmodium of malaria even after it has entered the blood. The most important of these drugs are mepacrine and paludrine. The latter has the added advantage that it also destroys the parasites inside any mosquito which bites a person who has been treated with the drug.

Yellow Fever, which is also carried by a mosquito, made it necessary to abandon the construction of the Panama Canal. Work was resumed when a team of scientists, the Reed Commission, identified the carrier. Several American army volunteers, who allowed themselves to be bitten by this mosquito during the investigations, died or had very narrow escapes.

Hygiene. Many of the carriers of disease-germs, as well as the germs themselves, thrive in warm, dark, moist and dirty places; so the most effective way of reducing the spread of disease is general cleanliness of the body and all that may come into contact with it. The vast improvement in private and public *hygiene* (Hygeia, Greek goddess of health), and the development of insecticides (insect-killers) such as D.D.T., have done much to raise the general standard of health in many countries. Constant alertness for the earliest signs of such diseases as tuberculosis and cancer has been made simpler by the development of mass-radiography, by which an internal inspection of the chest can be made in a few seconds, and at regular intervals.

Inoculation.

Special measures have to be taken against some diseases. The first successful attempt to control disease-organisms inside the body was made by *Edward Jenner* (1749–1823), who invented the process of *vaccination* (Latin: *vacca*, cow). It depends on the fact that a person who has recovered from an attack of cow-pox, which is a mild disease, seems to have acquired a technique which stands him in good stead when attacked later by germs of small-pox, which is a very serious disease. The body seems to "remember" how to make the substances (anti-toxins) which can render the germs harmless. In vaccination, therefore, a small dose of cow-pox germs is introduced into a scratch on the skin, causing slight fever. In overcoming this the body becomes proof against smallpox (but not against other diseases) for several years.

Other types of injection may be used to make people immune to certain other diseases. Sometimes germs of the actual disease, which have been cultured in conditions which make them weak, are injected. In other cases, dead germs of the diseases are injected, and the small amount of toxin which is associated with them is enough to stimulate the body to manufacture a surplus of anti-toxin, and to "learn" how to produce it quickly when the need arises. The process is called inoculation or immunization, and has proved very effective against typhoid, tetanus (lock-jaw) and other diseases in His Majesty's forces, and against diphtheria in children.

Other Types of Control.

An interesting example of control of plant-pests is that of rust of wheat. This disease, which destroys wheat-crops, is caused by a parasitic plant which spends part of its life on a barberry bush. Thus, by destroying the barberry bushes near a wheat field, the disease can be checked. It was discovered in 1947 that the spores can travel over one thousand miles (they were found alive in the air over the Arctic ocean), so the destruction of nearby bushes is not a guarantee of freedom from the pest in any particular wheat field.

Control by natural enemies. A modern method of control which, if carefully planned, can be very effective, is based on the old custom of keeping a cat to keep down the mice. Early experiments along these lines sometimes produced surprising results, for the organisms which were encouraged to destroy the pests were so successful that they completely eliminated the undesirable organisms, and then, having lost their source of food, turned their attacks to other animals or plants, and soon became a bigger nuisance than the pests they had removed. Bitter experience soon showed that biological control is a very intricate business, and special techniques and prolonged study of each problem are needed if it is to succeed. A remarkable example of its success is the control of the prickly pear in Australia.

This plant, which forms impenetrable thickets, covered 50,000,000 acres of Queensland. In 1926, a moth whose larva bores into the plants and weakens them was introduced from the Argentine. By 1933, the country was completely clear of the prickly pear, and it was calculated that the larvæ must have eaten at least 15,000,000,000 tons of it.

Control of weeds by manuring. At the Rothamsted experimental station it is possible to see a field, one half of which is literally covered with weeds, while the other half, which is not separated from it in any way, is perfectly free from them, and contains nothing but grass. The secret is in the fact that the two halves of the field are regularly treated with different kinds of artificial fertilizer: and experiment has shown that some fertilizers encourage the growth of weeds while others prevent it. The application of this knowledge is not yet very widespread, but has great prospects for the future.

Enough has been said about the control of organisms to show its importance, but you would do well to pursue the topic further yourself by reading and discussion, and by finding out all you can about the public health and cleansing services of your town or neighbourhood. You will find many aspects, such as refuse-destruction, purification of drinking-water, and fumigation of infected premises, which are important, but there is not space for discussion of them in this book. More examples of control are given in books dealing with food-preservation, antiseptics, pet-rearing, etc.

QUESTIONS

Section A.

1. Name three animals and three plants which you consider to be essential to human beings, giving reasons.
2. Name three animals and three plants whose destruction you would consider to be beneficial to human beings, giving reasons.
3. What daily steps do you personally take to control undesirable organisms in your environment?

4. Describe three examples of the control of desirable plants, showing what improvements are thereby brought about.
5. Write notes on immunization, antiseptics, insecticides.
6. Describe three examples of biological control of undesirable animals by encouraging their natural enemies.
7. What is hygiene? Describe the objects and some of the methods of public hygiene.
8. What is the purpose of the large wooden discs which are often seen fastened round the mooring-ropes of ships lying in harbours?

SECTION B.

1. "The insects are a group of organisms we could very well manage without." State the arguments for and against the above opinion.
2. What are the advantages of asepsis in surgery, and why is asepsis practically confined to operating theatres, whereas antisepsis is practised almost everywhere?
3. Write an essay on "The Public Health Services".
4. Public health and cleansing are usually far more highly developed in towns than in rural areas. Why, then, is it generally considered more healthy to live in the country?

CHAPTER XVII

IRRITABILITY

Every organism responds to various types of stimulus; that is, certain features or happenings in the organism's environment produce definite changes in the organism itself, resulting frequently, but not always, in some form of movement. A simple example of this is provided by the fact that almost any vertebrate will move in response to a sudden loud noise. Similarly, a green plant moves some of its parts in the direction from which light is coming: but in this case the response is much slower, and is brought about partly by adjustment in the growth-rate of different parts of the plant.

The response to one stimulus may often be modified by the presence of other stimuli: as when a root, which normally grows downwards in response to the stimulus of gravity, grows in some other direction towards a water supply (page 230). It is the combined effect of very many stimuli which controls the normal development of an organism. In other words, the normal development of an organism is a continual process of reaction between the organism and its environment. It is therefore often difficult to trace a particular action to a single stimulus. For this reason, experiments on irritability should be very carefully devised and care taken not to misinterpret their results, especially with higher organisms, whose reactions are usually extremely complex.

> Inquiry 97. It is a common trick among young people to walk up behind, and to one side (say the left) of a companion, and snap the fingers close to his ears on the other (right) side. This causes him to turn the wrong way, and look rather foolish. This is because one judges the direction in which a sound approaches by its relative effect on the two ears, and naturally expects the newcomer to be on the same side as his fingers.

Reception of Stimuli.

The simplest organisms receive stimuli through the general body-surface. Thus, if any part of amœba is touched with a needle the whole animal contracts: but if a piece of food touches the animal only the neighbouring parts of the body respond by forming pseudopodia to engulf the food.

This method of receiving stimuli is efficient only in very simple organisms, and when higher animals are examined it is found that advancement in general organization of the body is usually accompanied by the appearance of special methods of receiving and responding to stimuli. In hydra, for example (page 185), each cnidoblast comprises a complete system for receiving and responding to stimuli of touch. In addition, there is a network of *nerve-cells*, specially concerned with transmitting throughout the body a stimulus received at any point on its surface: and with co-ordinating the response of the muscle-cells to the stimulus so that they work in harmony, thus producing an appropriate movement of the whole animal as an individual.

Sense-organs. The nerve-net of hydra, while an advance on the condition in amœba, is still suitable only for small and simple animals. Most animals have special groups of tissues, each concerned with receiving a particular type of stimulus. These groups, called sense-organs, have means of transmitting their message to some other part of the body, where it is recorded, interpreted, and another message sent out to those parts of the body which will be involved in making the appropriate response. Such an arrangement is called a *nervous system*, because the messages are transmitted along thread-like tissues called nerves. It is crudely developed in the earthworm (page 188), but is seen at its best in the vertebrates, and reaches its highest level of development in the mammals.

The Nervous System.

The structure of the principal sense-organs of a mammal is described in Chapter XIX, and at this point we shall be content with a general outline of the nervous system as it is found in human beings.

The five main senses of Man are *sight*, *hearing*, *touch*, *taste* and *smell*. Some of these have fairly distinct subdivisions, as, for example, in sight, the two distinct functions of colour-vision and appreciation of light and shade. Each sense has its special organs for the reception of stimuli, and these organs are normally unaffected by any other type of stimulus. If, by some artificial means, they receive a "foreign" stimulus, the response may be misleading. Thus, if the terminals of a flashlamp battery are placed on the tongue, a salty taste is experienced. Similarly, a severe blow or an electric shock between the eyes, causes the victim to "see stars"—that is, it produces in the brain an effect which is mistaken for light-stimulus.

The brain is a large mass of nervous tissue, consisting of several distinct regions. The largest, which deals with messages from the sense-organs, is called the cerebrum. It is divided into right and left hemispheres (Fig. 106) and has a grey outer layer, much folded, called the cortex. Certain regions of this cortex are specially concerned with messages from particular sense-organs, as, for example, the auditory area, the visual area, the olfactory (taste and smell) area. Messages are received from the sense-organs along *sensory* nerves, and are interpreted by the brain as sensations. Other messages may then be sent back to the same or other parts of the body, and if these messages are to produce muscular action, they travel along motor-nerves.

The brain, then, receives stimuli, records sensations, and originates actions. It is capable, in Man, of initiating actions and activities (especially mental activities), for which there may be no traceable stimulus. It also controls many acts which are originally involuntary. Thus, it enables a person to remain awake, if he so wishes, long after he would normally have fallen asleep. Even the purely involuntary actions are often controlled by the brain—but this time by the hind portion, or *cerebellum*.

The brain is the seat of memory, understanding and will. This does not mean that "brain" and "mind" are just two terms for the same thing. The *mind* is the powers of the soul in action: and the brain is the material part of the body through which they function.

Transmission of stimuli. When it reacts to a stimulus, a sense-organ sends a message along a nerve to the brain. The transmission is partly electrical, at any rate between sixty and two hundred miles per hour. Many nerves from one sense-organ may lie side by side, forming a fairly thick cord, as in the optic (Greek: sight) and auditory (Latin: hearing) nerves. As most of the sense-organs (eyes, nose, tongue, ears) are in the head, these nerves pass directly to the brain; but the nerves of touch and pain, and motor-nerves for all the rest of the body, pass down inside the vertebral column as part of a substantial bundle of nerve-fibres (the *spinal cord*), from which they emerge between the vertebræ to link up with the parts of the body which they serve.

Reflex action. Sometimes the message from a sense-organ, especially one of pain, requires an instantaneous answer. In such cases, instead of following the normal course through the brain, the message is short-circuited in the spinal cord, and the response originates there. This happens, for instance, when one's finger accidentally touches a hot surface. A message flashes from the finger, and as soon as it reaches the spine a return message set out from the spine along a motor-nerve, which causes the arm-muscle to contract and draw the finger away from the hot surface, even before the brain feels the pain (Fig. 107).

Some reflex actions, such as the unconscious balancing of muscle-actions in walking or swimming, pass through the cerebellum. Many actions which are themselves reflex can become associated with reactions occurring in higher levels of the brain. They are then called "conditioned reflexes." An example of such an action is the fact that the mere thought of a tasty meal can make the mouth water—that is, it makes the salivary glands come into action: an occurrence which would normally be a simple reflex response to the stimulus of food in the mouth.

Sympathetic Nervous System.

There is a system of nerves concerned with purely involuntary activities, such as the beating of the heart and the working of the digestive system and glands. This is called the *Sympathetic nervous system*, and although linked up with the remainder of the nervous system it is a distinct organization alongside it, and able to function when the latter is out of action, as in deep sleep or anæsthesia. This system controls all the smooth or unstriped muscles of the body, which are incapable of voluntary control.

Irritability in Plants.

Some detailed examples of this are considered in Chapter XVIII, but it will be useful here to point out some of the differences between this function in plants and in animals.

No plant has a nervous system. Some of the simplest (unicellular) plants possess an *eyespot*, which is believed to be sensitive to intensity of light: and of course all green plants are so sensitive. We have seen that the chloroplasts turn themselves so as to make the best use of what light is available (page 100). In addition, the organs of plants are often light-sensitive as units, as is seen in the closing of flowers at night. Parts of some plants are sensitive to touch as, for example, the *Sensitive Plant* (a species of mimosa), whose leaves fold up when touched.

It appears that the response of plants to stimuli is usually first a chemical response, followed in some cases by physical changes brought about by adjustment of osmotic pressure, which in turn affects the water-content of certain cells, and in other cases by changes in the growth-rate. At any rate, any messages which are transmitted through the tissues must be carried by chemical substances (hormones). This method is also employed in animals in addition to the nervous system (page 154).

In general, the response to stimulus in plants is much more delayed than in animals, and when it does occur is usually less spectacular.

QUESTIONS

SECTION A.

1. What is meant by the terms: stimulus; response; sensory; motor?
2. Name four organisms as examples of stages in the increasing organization of mechanism for carrying out the function of irritability, and write a brief comparison of their methods.

3. Describe what happens in an animal such as a frog or rabbit, between the reception of a stimulus of touch (a prod with a blunt instrument) and the operation of the response.
4. What is a reflex action? Draw a simple diagram to show the course of the nerve-impulses in such an action.
5. What are the essential features of a central nervous system?
6. Draw a sketch of the human brain, showing the main functions of each part.
7. Give three examples of response to stimulus in plants, stating in each case how the stimulus is received by the plant.
8. Make a labelled drawing of a nerve-cell.

SECTION B.

1. What are the advantages of a central nervous system as compared with the nerve-net in such an animal as hydra?
2. Explain why a cold in the head often produces "singing" in the ears and causes food to taste strangely.
3. Why is it dangerous to drive a car when "under the influence of drink"?
4. Compare the sensory efficiency of hydra with that of a mammal.

CHAPTER XVIII

PLANT MOVEMENTS

MOVEMENT is not usually considered as a common feature of plants: yet all plants show *irritability* as one of their vital functions, and some of the lowest forms of plant-life, in performing it, show *motility* (moving from place to place), usually by swimming. This type of movement, involving the whole organism, is called *taxis*, the commonest type being *phototaxis* (movement towards light), and is usually brought about by the lashing of a pair of protoplasmic theads, called flagella, as in the case of chlamydomonas (Fig. 95).

In the multi-cellular plants, the power of moving freely is lost by the organism as a whole, but is still possessed by the male gametes of many of the thallophyta (page 196), the mosses and the ferns. In all these cases the movement is called *chemotaxis* (movement in response to a chemical attraction), and the necessary stimulus is provided by a chemical secreted by the female organs. There must be a film of water through which the gamete can swim.

The higher plants have lost the power of motility completely. Movement in these plants may be of three types: movement resulting from different rates and directions of growth (tropisms); movements of fully-grown parts (nastic movements); and passive movement of detached parts of the plant, which are carried by wind, water or animals. This last type of movement, although very important to the plant, is only included here for the sake of completeness, as it is largely dependent on agents outside the plant. The other two types of movement, although stimulated by outside agents, are really carried out by the plant itself.

Tropisms.

The most obvious way in which parts of a plant may move in relation to each other is by growing at different rates or in different directions. Such movements are called tropisms (Greek: turning), and occur in response to some stimulus outside the plant, such as the force of gravity (geotropism), direction of light (phototropism), presence of water (hydrotropism), etc.

A tropism is said to be positive when the parts grow towards the stimulus, and negative when they grow in the opposite direction.

Geotropism. Primary roots of flowering plants are positively geotropic. If you refer back to Inquiry 4, you will see that, no matter what the position of a seed, the radicle turns downwards as soon as it bursts through the testa. Curvature continues until all sides of the root are equally exposed to the force of gravity (i.e. the root is growing vertically downwards).

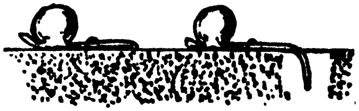

FIG. 98.—Geotropism.

INQUIRY 98. Fill a shallow box with sand to within a quarter of an inch of the top. The sand should be firm enough to allow the box to be stood on edge without spilling. Press soaked peas into the sand, with all their radicles showing and pointing to one side of the box. Cover it, and stand it on edge so that all the radicles point vertically downwards. Seedlings will thus develop straight radicles and plumules, and will be useful for the following Inquiries.

INQUIRY 99. Fix seedlings horizontally on wet sand, keeping them in place with staples of copper wire (avoid damaging the seedlings). Place a loose lid over the tray to exclude light. The roots will turn into the sand. How would you try to show that it is not just the moisture which causes the curvature?

INQUIRY 100. Attach young seedlings to a klinostat (a turntable which can be rotated at controlled speed in any direction) as in Fig. 99. Rotate the turntable at the rate of one revolution per hour. This causes the force of gravity to act equally on all sides of the root, and no curvature occurs.

INQUIRY 101. Set up the apparatus as before, but this time rotate the table rapidly. The effect of gravity is neutralized as before, but a new stimulus, centrifugal force, is introduced, and the root responds positively, growing outwards along a radius.

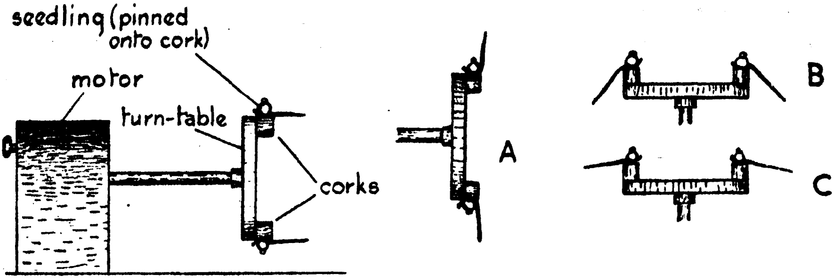

Fig. 99.—Klinostat.

Inquiry 102. Repeat Inquiry 101, with the table horizontal. This time gravity acts normally, causing downward curvature; but centrifugal force also acts, and the root takes up a position which expresses the combined effects of these forces. Thus, if rotation is very rapid, the root will be almost horizontal; while if it is slower the root will point outwards and downwards.

The shoots of plants are negatively geotropic; that is, their response to gravity is exactly the reverse of that just described for roots: and if the same inquiries are carried out in darkness they will serve just as well for the shoots.

Phototropism. The green parts of plants, and especially the leaves, are positively phototropic—they turn towards the light. To be quite precise, the leaf-blades turn to present their surfaces at right-angles to the light. This is sometimes called diaphototropism. If a plant has been near a window, in a room, for some weeks, the leaves and perhaps the stem will show a distinct leaning towards the light. By turning the plant round, and leaving it for some days, the process of phototropism may be seen in action. Curvature sets in which would eventually turn the leaves once more to the window. If it is desired to keep ornamental plants growing near a window, symmetrical in form, they should be turned regularly to neutralize the effect of phototropism.

The buds (not open flowers) of the sunflower plant follow the "passage" of the sun across the sky —hence the name of the plant.

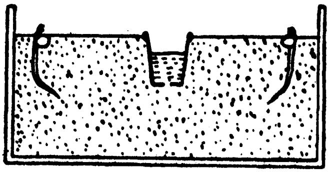

Fig. 100.—Hydrotropism.

Some roots are negatively phototropic, especially those developed in the air instead of in the soil. The mistletoe is an example (page 209). Normal roots seem to be insensitive to light.

> INQUIRY 103. For inquiries on phototropism, which you should be able to devise for yourself, it is useful to have a light-proof box about two feet by nine inches by nine inches, with an adjustable shutter at one end. This apparatus is big enough to take a young plant in a small plant-pot. Your inquiries should test the effect of change of intensity, as well as direction, of light.

Hydrotropism. The roots of plants are positively hydrotropic; that is, they grow towards a water supply. Normally this tropism works in harmony with their positive geotropism; but the hydrotropic effect is stronger than the other.

> INQUIRY 104. Set soaked seeds in fairly dry sand and bury a plant-pot in it as in Fig. 101. Pour water into the plant-pot. When the seeds have germinated, remove the seedlings carefully. It will be seen that the roots all point towards the water in the plant-pot.

Region of curvature. It has been stated early in this chapter that the types of movement just described are achieved by alterations in the growth-rate. This can be demonstrated easily in the case of roots.

> INQUIRY 105. Mark off a straight radicle at intervals of one millimetre, by touching it with a stretched thread dipped in Indian ink. Carry out Inquiry 104 with this seedling. It will be seen that the marks in the curved region are now more than one millimetre apart, showing that curvature took place in the part of the radicle which was increasing in length.

Tendrils. It was seen on page 34 that many climbing plants attach themselves to a support by means of tendrils. These are slender structures, straight and soft when young. Their tips move continually as they grow in a small spiral (circumnutation). This increases their chances of touching a support. As soon as a support is reached, the friction of one side of the tendril against it causes the other side to grow much more rapidly. This bends the tendril round the support, and as the contact increases so does the stimulus until the tendril is tightly coiled round its support. After this (note, not before—the tendril was originally straight) the part of the tendril between the support and the stem of the climbing-plant becomes spirally coiled also, forming a spring-connection which lessens the chance of damage due to wind or plucking.

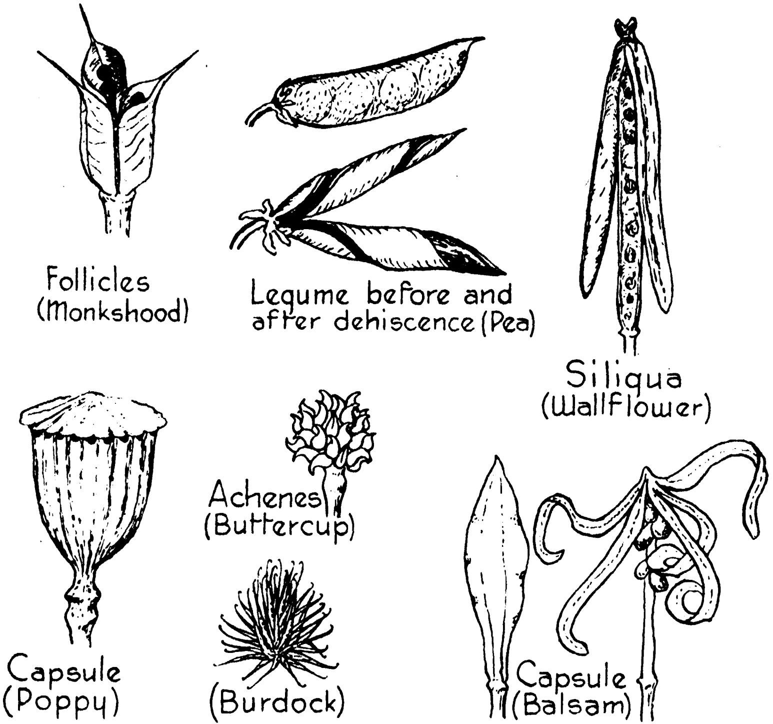

FIG. 101.—Examples of dry fruits.

INQUIRY 106. Stroke one side of a tendril of a growing plant of White Byrony steadily for about two minutes. A pronounced curvature is caused as described above. Fasten a small piece of plasticine on one side of another tendril. No curving is seen within a reasonable time (say two hours), showing that it is friction, and not simple contact, which induces curvature.

Stem-twiners. Plants, like the convolvulus (page 20), whose stems twine round a vertical support, must use some other mechanism for the direction of twining is usually constant for a particular species (clockwise growth in convolvulus, counter-clockwise growth in honeysuckle), and cannot be induced by friction.

Chemotropism. Sometimes the direction of growth is influenced by chemicals as, for instance, sugar on the stigma of a flower induces the pollen-tube to grow into the style.

Nastic Movements.

Fully-grown parts of plants are often capable of considerable movement. Well-known examples of this are the opening and closing of flowers, the rapid recovery of an erect position by grass which has been trodden down, the drooping of the sensitive plant (Mimosa pudica) when touched, etc. In all these cases the movement is brought about chiefly by changes in the water-content of certain cells, along with special distribution of cell-thickening which sets up strains in particular directions as the water-content of the cells increases.

This type of movement has already been described in the case of stomata (page 91), and it was seen that the changes in water-content are brought about by osmosis. If the change is reversible (as in stomata, and the opening and closing of petals) it is usually osmotic. If it is irreversible (as in the ejection of fruits, seeds or spores) it may still be osmotic, but is more often the result of simple dehydration or drying-up of certain tissues.

> INQUIRY 107. Find out, by placing black bags over them, whether it is just the approach of darkness, or the lateness of the hour which causes the closing of composite flowers (Ox-eye daisy, for instance). The experiment should be carried out on growing plants, not cut flowers.
>
> INQUIRY 108. Lay a sheet of paper flat on a table with its edge protruding about an inch. Breathe heavily on the protruding part. Explain what happens in the next half-minute.

Dispersal of Fruits and Seeds.

This topic is discussed in Chapter XX from the standpoint of fruit-structure. Here we are mainly concerned with those types of dispersal where the plant itself is largely responsible for the movement of the parts.

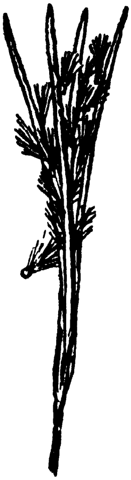

FIG. 102—Ripe fruit of Rose Bay Willow - Herb, showing parachute-seeds.

Dehiscent fruits (Latin: *dehiscens*, splitting). The simplest type of dehiscent fruit is the *follicle* (Latin: little bag), as seen in the monkshood (Fig. 101), where each carpel, containing seeds, splits down the inner edge and the seeds are gradually shaken out as the fruit sways in the wind.

A much commoner arrangement is the *capsule*, which may be quite elaborate (Poppy, Fig. 101), opening only at the top by pores, or a simple tube which splits like a banana-skin (willow-herb, Fig. 102). The poppy-capsule is on a stalk which, when bent over by the wind, springs back into place, shaking out the seeds. The seeds of the willow-herb have each a parachute of stiff hairs, enabling them to float away on the breeze.

Fruits which propel their seeds. In many fruits, the drying-process sets up strain in the tissues, so that the splitting, when it occurs, is sudden, and the seeds are jerked away from the parent plant. In a clump of gorse on a hot sunny day in late summer, there is a continual popping noise as the capsules explode, shooting out their seeds. The violet and the garden geranium are other examples (Figs. 10, 101). A gentler form of propulsion is seen in leguminous plants, such as the pea, where the fruit-case splits down both its edges, and the two segments, carrying the seeds, then curl away from each other, forcing off the seeds in turn (Fig. 101).

Spore-capsules. The dispersal of spores in the pin-mould is described on page 204. This is interesting as an example of dispersal, not by drying-up, but by water-intake. The spores of mosses are contained in a capsule which is enclosed in damp weather by a lid consisting of a series of tooth-shaped flaps. When the atmosphere is dry these curl outwards, and spores are shot out by little strips of springy tisssue in the spore-case (Fig. 103).

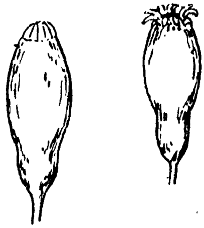

FIG. 103. — Moss-capsule, closed and open.

Airborne fruits and seeds. Airborne fruits are of two kinds: those with wings; and those with parachutes. Winged fruits are usually formed on trees where they have a good distance to fall, and so can glide away. Examples are the ash, elm, sycamore and lime (Fig. 25). Fruits with parachutes are formed in the dandelion, thistle, and many other composites. We have already seen that seeds, as distinct from complete fruits, may be dispersed in this way (willow-herb).

Dispersal by animals. This is described in some detail in Chapter XX. As the movement is entirely passive on the part of the plant, there is no need to discuss it in this chapter, except to say that it dispenses with the necessity of locomotion in the adult plant, as does every form of seed dispersal.

Dispersal by water. This mode of dispersal is very rare in this country. The fruits of the water-lily have a spongy tissue attached, which only slowly becomes water-logged, by which time the fruits have been carried some distance from the parent-plant. A similar arrangement, on a much bigger scale, is found in the coco-nut.

In conclusion, we must refer to yet another type of nastic movement which has been mentioned on page 34. That is the response of insectivorous plants such as the sundew and Venus' fly-trap to the touch of an insect. Although the insect may touch only a small area of the leaf, the entire leaf responds. This serves to point out a fact which applies to other forms of irritability in plants, both tropic and nastic; namely, that although plants have no system of nerves corresponding to those in animals, there must be some means of transmitting stimuli through the tissues, because very often the response comes from a much wider area than that which directly experience the stimulus. It is believed that the message must be transmitted by chemical means, and the substances carrying the messages are called hormones (see page 153).

QUESTIONS

SECTION A.

1. What is the difference between tropic and nastic movements? How would you show that it is only the growing parts of a root which curve under the influence of gravity?

2. What are the benefits which a plant derives from the operation of geotropism?
3. How would you show that the shoot of a garden geranium is phototropic?
4. Write short notes on phototaxis, chemotaxis, sleep-movements, as these terms apply to plants.
5. Discuss the advantages and disadvantages of the immobility of plants.
6. Explain with the aid of diagrams how nastic movements aid in the dispersal of any three named fruits or seeds.
7. How can the effects of geotropism and hydrotropism on roots be investigated separately?
8. State, giving reasons, what you would expect to happen if by artificial means the only water available to a plant were kept at a higher level than the base of the root system.

SECTION B.

1. Compare the irritability of a simple flowering plant (e.g. buttercup) with that of hydra.
2. Describe the tropic and nastic movements involved in the pollination of a named flower from this list: lupin, orchid, sage.
3. Describe the tropic and nastic movements in the fertilization of any named flower.
4. Describe what inquiries you would perform to investigate phototropism in one of these plants: wood-sorrel, daisy, mushroom.

CHAPTER XIX

NERVES AND SPECIAL SENSES

THIS chapter deals with the nervous system, and the special senses, mainly of sight and hearing, in mammals. Before reading it you should revise Chapter XVII.

The nervous system of a mammal is divided into two main parts—the *Central Nervous System*, consisting of the brain and the spinal cord, and the Peripheral Nervous System, which includes all the other nerves in the body. The main point of difference between the two sets of nerves is that the C.N.S. is completely encased in bone, while all the other nerves run, at least partly, through fleshy tissues. There is not so clear a difference between their functions, because most of the peripheral system is linked up with the C.N.S. and the two work in close harmony with each other.

Nervous Tissue.

Nervous tissue consists of bundles of *nerve-cells* (neurons). The neurons are cells of a special type, seen in Fig. 104. They are bundled together, end-to-end and side-by-side, and enclosed in a sheath. Such a bundle of neurons makes up a nerve, and the spinal cord consists of many hundreds of these nerves, again lying end-to-end and side-by-side.

A *neuron* is a single nerve-cell. The main body of the cell consists of dense protoplasm, with a prominent nucleus, and a number of projections. Most of these are short and branched (dendrites), and carry messages into the cell. There is one long projection, which may reach a length of several feet in a large animal. It is called an axon, and messages travel along it from the body of the cell. The distant end of the axon is split up into fine branches like a small brush. This axon-brush may pass on its message to the dendrites of another neuron, or it may be situated in a muscle (motor nerve) or in the brain or spinal cord (sensory nerve).

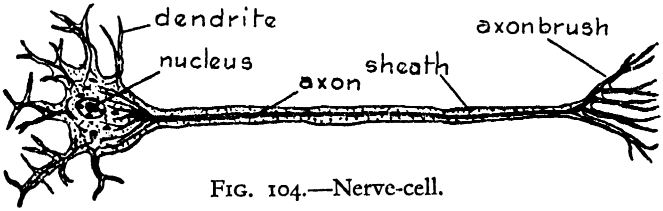

FIG. 104.—Nerve-cell.

All nervous tissue, including that of the brain and spinal cord, shows two distinct consistencies—the *grey matter* and the *white matter.* The grey matter consists mainly of the cell-bodies of neurons, while the white matter consists of bundles of axons, forming nerve-fibres. Little masses of nervous tissue, as distinct from the slender nerve-fibres, are found in various parts of the body, and each is called a ganglion (Greek: knot). The biggest of these is the *solar plexus,* which is just below the stomach, and forms an important link in the sympathetic nervous system.

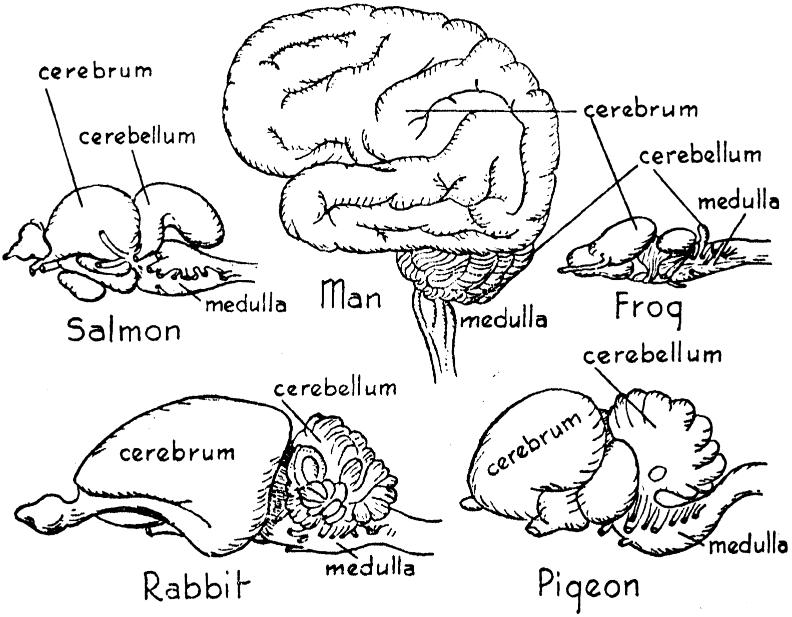

FIG. 105.—Brains of vertebrates, showing relative sizes.

Brain and Spinal Cord.

The brain is a large and complicated mass of nervous tissue. In mammals, the brain-weight is a greater fraction of the body-weight than in any other animals: and in Man the brain is relatively heavier than in any other mammal. Along with this progressive increase in brain-weight there is an increase in the weight of the cerebrum compared with that of the rest of the brain (Fig. 105). Do not imagine that brain-power depends only on the relative weight of the brain. One of the heaviest human brains ever known was that of an idiot.

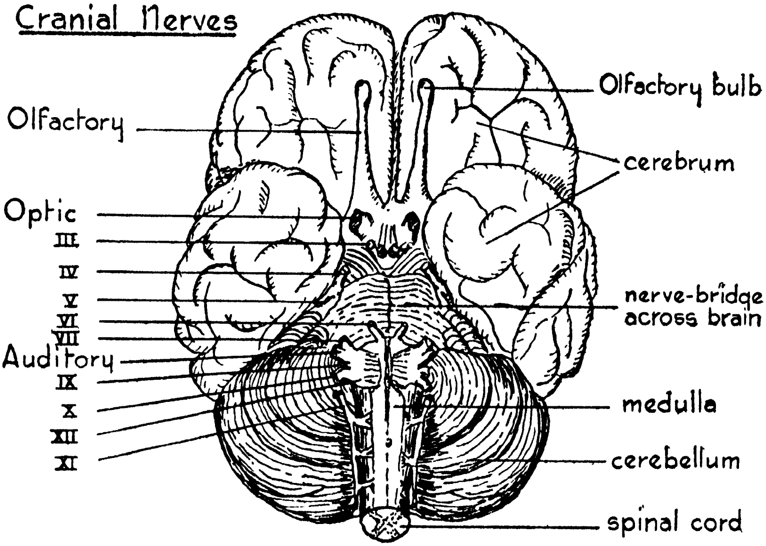

FIG. 106.—Human brain from below.

The general shape of Man's brain can be seen in Fig. 105. The *cerebral hemispheres* are the most prominent features, and their surfaces are very much folded (convoluted). The outer portion (cortex) of the cerebrum is grey matter, while the internal tissue consists of white matter. The rest of the brain is almost hidden by the cerebrum, so Fig. 106 shows the ventral view, in which the mid-brain and hind-brain may be seen.

Various regions of the brain are particularly concerned with certain activities; thus, the cerebrum controls the voluntary muscles and the mental processes, and receives and interprets messages from the special sense-organs. A strange feature of this last function is that messages to and from the left eye, ear, etc., are dealt with by the right cerebral hemisphere, and vice versa. The messages cross the brain by means of a bridge of nerve-fibres.

The *cerebellum* ensures that when many muscles are involved in an action, such as walking, they all work in harmony. The hind part of the brain, which leads into the spinal cord, is called the *medulla*, and exerts a general control over the working of the sympathetic nervous system.

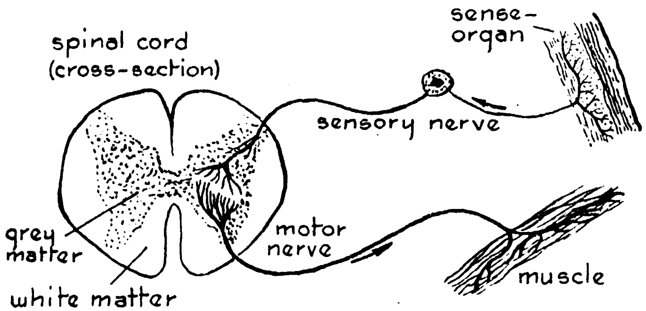

FIG. 107.—Reflex-arc (diagrammatic).

The *spinal cord* (Fig. 107) is seen in cross-section to consist of an outer layer of white matter, and an inner core of grey matter. This grey matter appears in cross-section in the form of a letter "H". There are two deep narrow grooves in the cord, one dorsal and one ventral, making the centre portion quite thin. There is a very narrow canal running down this centre portion, so the cord is hollow (contrast the solid cord of invertebrates). From the arms of the "H" on each side arise the roots of the spinal nerves. The dorsal and ventral roots of each nerve come together just outside the cord in a common trunk which comes out between the vertebræ and connects the spine to some other part of the body. Sensory messages enter the upper (dorsal) arms of the "H" and motor messages leave the lower arms. Messages to and from the brain travel along the cord in the white matter.

You should now be able to realize how an injury to the spine may result in paralysis of the body below the injury; the spinal nerves may be crushed, and so the connection between the brain and the lower part of the body is interrupted. Sensation and mobility are lost, but blood-circulation and other functions may go on working, because these are controlled mainly, though not entirely, by the sympathetic system. A proof that this system is not quite independent of the C.N.S. is the fact that, when the spine is dislocated near the base of the skull, as in hanging or in killing a rabbit with a rabbit-punch, death is instantaneous.

If one side of the brain is injured it may result in paralysis of the whole of the other side of the body. An interesting fact about the brain is that, in spite of its delicate nature, it is itself insensitive to pain, and operations can be performed on it without the need for giving the patient an anæsthetic.

The brain sometimes misinterprets messages. Thus, a person who has had part of an arm amputated often experiences the same sensations as if the hand were still there. This is because any message entering the nerves which used to serve the hand will still be interpreted as coming from the hand.

> INQUIRY 109. Sit upright with the knees crossed until the upper leg "goes to sleep". (This is because you have stopped the blood supply at the knee, to the nerves which serve the lower part of that leg.) Now stand up, and notice the tingling in the foot, as the blood returns to the nerve. Although it is at the knee that the blood supply was restricted, the brain interprets the sensation as coming from the foot.

Cranial nerves. Since the special sense-organs of a mammal are mainly in the head, the nerves connecting them to the brain do not pass through the spinal cord but go directly through the brain-case, or *cranium*, and so are called cranial nerves. A few cranial nerves are not concerned with sense-organs: as, for example, the vagus (Latin: wandering) which sends branches to the heart, lungs and intestines. A list of the cranial nerves is seen in Fig. 106.

The Eye.

All vertebrates have eyes which are similar, in their main structure, to a human eye. In fish, amphibia, reptiles, birds, and most of the mammals, there is one eye on each side of the head. This enables them to see objects almost all round them; that is, the animals have a wide *field of vision.* The hare, for instance, can look with both eyes at an object directly behind it without turning its head. In the higher mammals, the eyes are rather close together on the front of the head, and while this lessens the field of vision it makes these animals better able to judge distance. The reason for this will be seen later.

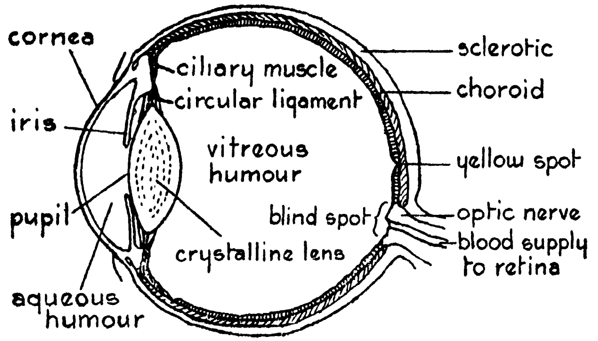

FIG. 108.—Horizontal section (seen from above) of right eye of Man.

The structure of a mammal's eye is most easily seen by examining the eye of an ox or sheep, which can be obtained from a slaughter-house or through a butcher. The eye rests in a bony socket which protects it. The eyeball is roughly spherical and has a very tough outer wall called the sclerotic (Greek: *scleros*, hard) which is opaque, except for a transparent window in front, called the *cornea.* This also is very tough, as its name (Greek: horny) implies.

Just beneath the sclerotic is a second layer, the *choroid*, which is well supplied with blood-vessels, and is almost black, so that light, once it has entered the eye, is not reflected out again. Just behind the cornea the choroid changes to a flat coloured layer, the *iris diaphragm*, with a central opening, the *pupil*, which is round in the ox and most mammals, but in the cat is a vertical slit. There is a muscle bordering the pupil, and the size of the opening varies according to the intensity of light. Behind the iris diaphragm is a *crystalline lens*, which hangs from the edge of the choroid by a circular muscle and ligament. The lens is biconvex, like a reading-glass, and its curvature can be lessened by contraction of the suspending *ciliary muscle*, according to the distance of the object being viewed, so as to focus the image on the *retina*, which is a third and innermost lining of the wall of the eye. Some lower vertebrates can move the lens backwards and forwards.

The front portion of the eye, between the cornea and the lens, is filled with a salty liquid, the *aqueous humour*. The space between the lens and the retina is filled with a transparent jelly, the *vitreous* (glassy) *humour*.

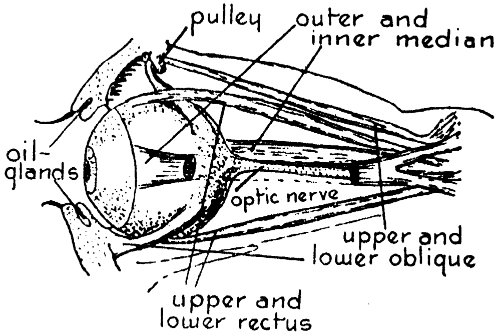

FIG. 109.—Eye muscles.

How the Eyes Work.

In the lower animals, each eye works independently. In the highest forms of mammals, the two eyes normally work as a single *visual apparatus*. Each eye is moved by three pairs of muscles (Fig. 109), but there is a nervous control which coordinates these movements so that normally both eyes are directed towards the same spot, which may be at any distance greater (in Man) than about four inches from the face. This gives a better idea of an object's distance, because the brain is aware of the effort needed to converge the eyes and learns to interpret this directly, as the distance of the object. Another useful point about *binocular vision* is that it enables the solid shape of near objects to be better appreciated, because each eye obtains a slightly different view and the two views are put together by the brain. This type of vision is also called stereoscopic vision (Greek: solid view).

INQUIRY 110. If you can look at an unfamiliar scene (where you have had no chance to judge distances), try first judging the distance of any object not more than ten feet away, *with one eye closed*. (Try, for example, threading a needle with one eye closed.)

INQUIRY 111. Hold a pencil at arm's-length in front of the face. Gaze at it, and bring it slowly nearer the face. At about six inches from the face you will be able to feel the pulling of the eye muscles, and soon afterwards the image will become blurred as the eyes find it no longer possible to converge steadily on the pencil.

INQUIRY 112. Repeat Inquiry 111 with one eye closed. This time the pencil can be brought nearer before the image blurs. The blurring here is due to the lens of the eye having reached its limit of curvature.

The cornea is kept clean, moist and lubricated by glands underneath the upper lid, which rapidly sweeps over the eye at frequent intervals. This is an example of muscular action which is normally involuntary, but can be performed voluntarily as well.

INQUIRY 113. Observe the rate of blinking of three fellow-students at a time when they are not aware of what you are observing (if they were, the rate might not be normal). See how long you can avoid blinking without acute discomfort.

Surplus liquid is drained away from the eye by a tear-duct, the opening of which can be seen at the lower inner corner of each eye. It leads into the nose—hence the need for nose-blowing when the eyes water. Near the tear-duct is a small fleshy fold which represents a third eyelid, which in birds, fish and many other animals, is highly developed as an extra protective covering which can be drawn sideways over the eye.

Light passing through the cornea must afterwards pass through the pupil. The size of this decreases if the light is strong.

INQUIRY 114. Look into a mirror. Observe the size of the pupil, and switch on a torch close to one eye. Note what happens to the pupil. Carry out a similar experiment with a cat, and note that the pupil almost disappears as a vertical slit. At night, the pupils of a cat's eyes become circular.

INQUIRY 115. Observe the patterns on the iris of your own and other people's eyes. The beautiful colour of a very young baby's eyes is due to the blood showing through the blood-vessels in it, before any colouring-matter appears in the iris itself

Light which succeeds in passing through the pupil next travels through the lens, and so through the vitreous humour to the retina.

Structure of the retina. The optic nerve enters the eyeball at the back, slightly to the inner side of the centre, and the nerves spread out all over the surface of the retina. Each nerve ends in a special light-receiving organ. In the human eye there are two kinds of these, called *rods* and *cones.* The centre of the retina (yellow spot), directly opposite the pupil, has only cones, and as we move outwards from the centre the number of cones decreases and the number of rods increases. The cones are specially sensitive to differences of colour, while the rods are specially sensitive to differences of intensity of light—that is, to light and shade. This explains why, in a dim light (e.g. twilight or starlight) we can see things more clearly if we look at them "out of the corner of the eye"—that is, in such a way that the light strikes the edges of the retina where the rods are most thickly distributed.

Where the optic nerve enters the eye there are no rods or cones, and this is called the *blind spot.*

> INQUIRY 116. Close the left eye and look at the dot below, moving the book slowly from about eighteen inches away towards the face. The cross on the right of the dot will disappear and then reappear. When it is invisible, its image is falling on the blind spot.

Although in the above inquiry the cross which disappears is on the right of the dot, in the right eye the blind spot is on the left of the centre. The image on the retina is reversed, like that in a camera.

> INQUIRY 117. Repeat Inquiry 111, but this time close the right eye and look at the cross. The dot will disappear.

There are blood-vessels on the retina in mammals (except in the centre, where they would interfere too much with vision).

> INQUIRY 118. Look steadily at a bright sky for ten minutes. You will become aware of little points of light swirling round at the edges of your field of vision. These are blood-corpuscles moving along the vessels on the retina.

At any moment when light is entering the eyes, the brain is receiving a continuous record of the effect of the light on each of the rods and cones in the retina of each eye. From all this information it builds up a picture which is the right way up, whereas the image in the eyes is both upside down and laterally inverted, like the image in a camera. The brain is so used to doing this that we are never aware of the process.

Special Kinds of Eyes.

Animals which only come out at night have no cones on the retina, and so are quite colour-blind. Many other animals are partly colour-blind, including cats and dogs, horses and bulls.

Birds have much more efficient eyes than mammals. The lens has greater power of accommodation (changing focus), and the retina is more closely set with nerves, so that the bird obtains a clearer picture. The retina has no blood-vessels on its surface, and this further improves the quality of the image.

In general, animals which are frequently hunted by other animals have a wide field of vision (rabbits, mice, sparrows), while those which hunt have their eyes facing forwards (dogs, cats, owls). There are many exceptions to this, because many hunting animals rely more on other senses than on vision.

Snakes have transparent eyelids which, though always closed for protection, cannot shut out the light. Some snakes can, however, close the pupil completely.

The Sense of Hearing.

The sense of hearing gives an animal the ability to experience sounds. A sound is caused by vibrations carried through some medium, normally air or water. Vibrations which may represent sound to one animal may not do so to another; for example, the human ear can only sense vibrations when they occur between about twenty times a second and twenty thousand times a second. A dog's ear can appreciate faster vibrations than this, which therefore represent sound to the dog, but not to a human being. Some dog-whistles give out a note of such high frequency, to which a dog will respond, although a human being hears nothing. There is slight difference in the sensitivity of normal human ears, so, for instance, some people can hear the scream of a bat and others cannot.

All vertebrates have organs showing a general similarity in structure to the ears of mammals; but in many cases they are used more in connection with the sense of balance than for hearing, and in all cases the two senses are closely connected.

The human ear will be described in detail, followed by notes on a few of the differences to be found in other animals.

The Human Ear.

Usually, when we speak of the ear, we are referring to the external flap which surrounds the entrance to the ear-passage. This is not an important part of the human ear, and if it were cut off the victim would still be able to hear quite well. In many mammals, however, the flap is a great help in collecting slight sounds, and indicating to the animals the direction from which they come. The muscles by which such animals move their ear-flaps are present, on a much-reduced scale, in human beings, and some people can control them, much to the amusement of their acquaintances.

The ear has three regions (Fig. 110): the outer, middle, and inner ear.

The outer ear consists of the flap, or pinna, and a short tube, about two inches long (in Man), which is lined with skin in which there are wax-producing cells. The wax, which should remain moist, traps dirt and germs, and protects the delicate lining from the effects of cold air. Sometimes too much wax is produced, and the ear becomes temporarily deaf. If the wax hardens in the passage it may become painful, and should be syringed out by a doctor. There is an old saying "Never put anything in your ear except your elbow", which is just a quaint warning that no object of any kind should be put into the ear, except by a doctor.

The inner end of the tube just described is closed by a very delicate stretched skin or membrane called the tympanum or *ear-drum*. This connects the outer ear with the *middle ear*. This is a space from which a narrow tube, the Eustachian tube, (Eustachio was an Italian doctor), leads to the back of the mouth.

This passage ensures that the pressure on the two sides of the ear-drum remains the same. When sound-waves enter the ear this balance of pressure is slightly disturbed, causing the drum to vibrate. These vibrations are carried across the middle ear by a group of bony levers called, from their shapes, the malleus (Latin: hammer), the incus (Latin: anvil), and the stapes (Latin: stirrup). The hammer is attached to the ear-drum, and the stirrup is attached to another smaller drum which separates the middle ear from the inner ear.

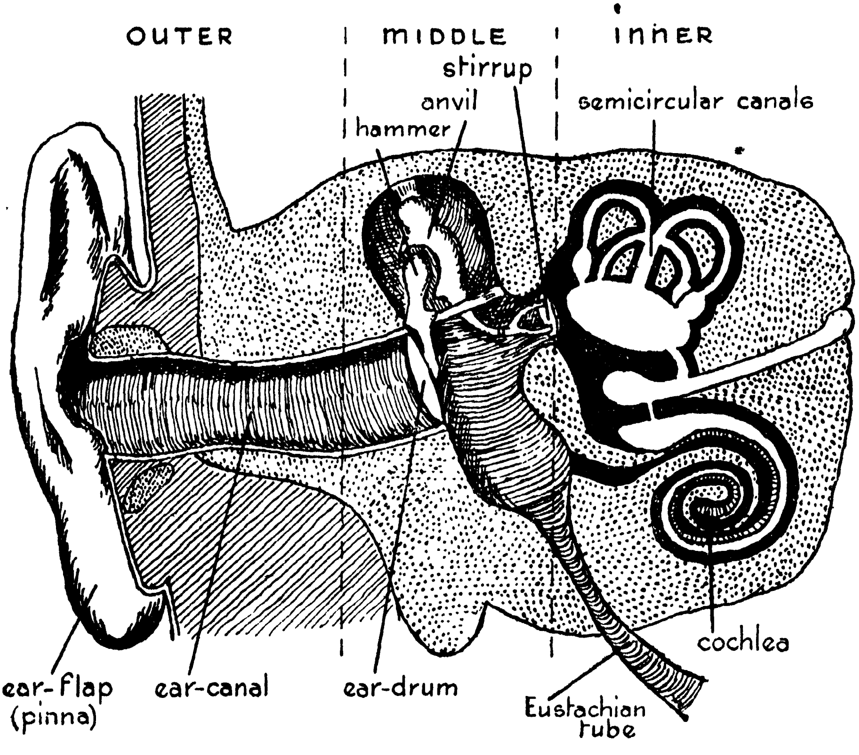

FIG. 110.—Vertical section through human ear.

The *inner ear*, unlike the other parts, is filled with liquid, and consists of two sections, the hearing section and the balance section.

The hearing section is a tube coiled like a snail-shell, called the *cochlea* (Latin: snail). The width of this tube decreases from end to end, and all along it are very sensitive nerve-endings sticking in through its wall. Vibrations of the fluid in the tube excites the nerve-endings and the auditory nerve carries corresponding messages to the brain which interprets them as sounds.

The balance section consists of three semi-circular canals which lie in three different planes at right-angles to each other. They all meet at one end in a small space called the utriculus (Latin: bagpipe). In this space are small particles of chalk. The whole apparatus is lined with nerve-endings. Whenever the position of the head is changed, the fluid in the apparatus swirls round, causing the chalk-particles to move, and stimulating the nerve-endings. From the messages which are transmitted from these nerve-endings the brain judges the position of the head, and sends out any messages which may be needed to preserve or restore the balance of the whole body. If a person whirls round several times and then suddenly stops, the fluid in the balancing-apparatus goes on whirling, the brain loses its sense of balance, and the person becomes giddy.

When a person suffers from a cold, the Eustachian tube may become blocked. This prevents adjustment of pressure on the inner side of the ear-drum, and may result in temporary deafness, or in continual "singing noises" in the head. Violent blowing of the nose, especially if one nostril is closed, may damage the ear-drum, or force disease-germs up the Eustachian tube. The ear-drum may also be burst by a very loud noise reaching it in the normal way. This often happens to artillery-men, unless they wear protective ear-plugs.

Other Types of Ears.

The ears of birds and reptiles are like those of mammals, except for the absence of the external flap; in the frog and other amphibia, the outer ear is completely absent, so that the ear-drum is flush with the body-surface (page 176). The frog has only one bone in place of the three described above in the middle ear. In fishes, the sense of hearing is very poorly developed, but the semi-circular canals are present, and in some fishes there are fairly large pebble-like pieces of chalk in the utriculus. In a large cod, these *otoliths* (Greek: ear-stones) may be as big as peas.

Other Organs of Special Sense.

We can only refer briefly to the other sense-organs. The sense of *smell* is poorly developed in Man by comparison with most vertebrates. This is reflected in the relative sizes of the olfactory lobes in the brains.

The sense of *taste* is probably keener in Man than in most animals, as is shown by the fact that few animals seek a wide variety in their diets. The human tongue has on it large numbers of small projections, called *taste-buds*, each of which has its own nerve-ending, and seems to specialize in a particular aspect of taste—sweetness, sourness, bitterness or saltiness. Taste-buds are also scattered over the inner lining of the mouth. Most of what we imagine as taste is really smell. This explains why it is a good plan to hold the nose when swallowing unpleasant liquids; though of course it is not possible to prevent some of the odour reaching the nose from inside the mouth.

> INQUIRY 119. Keeping the tongue as dry as possible, place, with the help of fine forceps, single grains of salt and sugar on various parts of the tongue. It will be noticed that no taste is observed until the substance dissolves. Notice too that sometimes the taste is not apparent because the grain was not placed on the correct type of taste-bud.

The sense of *touch* is distributed unevenly over the surface of the body. The nerve-endings are just below the surface of the skin, and by prodding very gently with a fine bristle on the cheek or other sensitive area, it is possible to find spots which are not sensitive to touch, because there is no nerve-ending immediately beneath them. By using two bristles at once one may show that when they are less than about one millimetre apart it is not possible to appreciate the two stimuli separately. This test can also be carried out by using a pair of dividers.

The sense of *pain* is distinct from that of touch, and has its own nerve-endings. They are mainly near the surface of the skin: and so a deep cut is no more painful, at the moment it occurs, than a shallow one, especially if the victim cannot see it. In humans, pain is very closely linked up with mental attitudes. Thus, an injury may really *feel* more painful if there is someone else there to witness it. A baby may injure itself and not know, if alone; but if someone sees the occurrence, the baby will cry, and probably feels pain which it would not otherwise have felt. For this reason it is probable that animals pay less attention to pain than we do; though it is quite certain that they do feel pain.

The sense of *position* is a very important one, but is so little appreciated that it has no common name. It is called the kinesthetic, or proprioceptive sense, and by its aid a person can tell at any moment without having to look exactly what is the position of all the limbs, and of the body as a whole.

QUESTIONS

SECTION A.

1. Describe briefly the central nervous system of a mammal, and state its main functions.
2. Draw and label a simple outline diagram of the human brain.
3. Give a list of the cranial nerves in Man, stating the main functions of each.
4. What is the work of the sympathetic nervous system, and how is it controlled?
5. Give a clear labelled diagram of the human eye, and describe briefly how it works.
6. How does a human eye distinguish between colour and intensity of light? What is twilight-vision?
7. Describe the structure and function of the human ear.
8. Write short notes on three of the human senses, excluding sight and hearing.

SECTION B.

1. Explain what is meant by a reflex action, and give two examples.
2. "The complex nervous system of a vertebrate would be of no advantage to an invertebrate." Explain this statement.
3. What is the working principle of hearing aids for deaf people?
4. People who are born deaf are often also dumb, although their speech-apparatus is perfect. Why is this, and how would you propose teaching such a person to talk?

CHAPTER XX

FLOWERS

FLOWERS are, with few exceptions, pleasant to look at, and so make a big contribution to the general beauty of the world. This fact should be borne in mind when considering the place of flowers in nature; but the more strictly biological function of a flower is to enable the plant to carry out sexual reproduction. In this way the plant completes its own life-cycle, and provides for the survival of the species to which it belongs. Many flowers also provide food, in the form of pollen and nectar, for animals; and these, in some cases, notably the bees, convert these materials into other substances, such as honey and wax, which are of value to Man. Flowers often produce pleasant-smelling oils which can be extracted and used as perfumes: and there is at least one example (cloves) of whole flowers being added to food as a form of flavouring.

The most important part of a flower is that which contains the sexual cells; but most flowers have also several other parts, each of which helps in the reproductive process. The flower-parts are modified leaves, arranged in whorls (rings) on a very much compressed portion at the tip of the flower-stalk. This compressed portion is called the *receptacle*, and is so short that the succeeding whorls seem to arise almost at the same level. The whorls, beginning with the lowest and outermost one, are called the *calyx* (Greek: cup), *corolla* (Latin: crown), *andrœcium* (Greek: male-container), and *gynœcium* (Greek: female-container). One or more whorls may be absent, but one at least of the latter two is always present (Plate VII).

There is great variety in the detailed structure of flower-parts, but they always bear some relation to the parts of the simplest flowers, of which the buttercup is an example. We shall therefore take this flower as a standard with which we can compare other types.

Flower-Structure.

The *calyx* is the most leaf-like whorl, being usually green and consisting of a ring of leaf-shaped segments called *sepals* (Latin: covering). The main function of the calyx is to protect the developing flower; so while formation is going on, the sepals completely enclose the rest of the flower, giving the familiar appearance of a green flower-bud.

When the bud opens, the sepals often curl back and become much less prominent. The buttercup has five sepals, as have many other flowers; but in monocotyledons the number is commonly three, and in the wallflower family, two or four. Sometimes, as in the primrose family, the sepals are united at their edges, forming a tube.

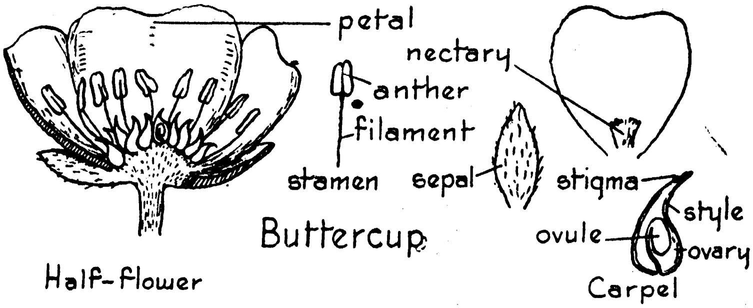

FIG. 111.

In some plants, such as the marsh marigold and most of the monocotyledons, the sepals may become brightly-coloured and take on the appearance of petals. In such cases, the petals may still be present (tulip, orchid, iris), in which case the petals and sepals together are called the *perianth* (Greek: outside-of-the-flower); or the petals may be absent (marsh marigold); or they may be modified for some other purpose, as in the globe-flower, where the petals are reduced to little flask-shaped receptacles full of nectar.

In composite flowers, where many flowers are massed into a single head, there is less need for each flower to have a protective calyx. This function is carried out by a group of bracts (page 35) which encloses the entire group of flowers. The sepals may in such cases be absent (daisy), or modified for some other purpose (dandelion, page 235).

The *corolla* is, in most flowers, the most prominent whorl, consisting of relatively large and often brightly-coloured segments called *petals* (Greek: leaf). They may be all alike, as in the buttercup, or some of them may differ in shape from others (larkspur, monkshood, orchid, etc.). If they are all alike, the flower is *radially symmetrical*; but if they differ in shape, the flower is *bilaterally symmetrical* (compare symmetry of animals, page 112). A bilaterally symmetrical flower is described as *zygomorphic*. This condition is found in flowers which are specialized for pollination (page 257) by a particular kind of insect, such as a bee or butterfly.

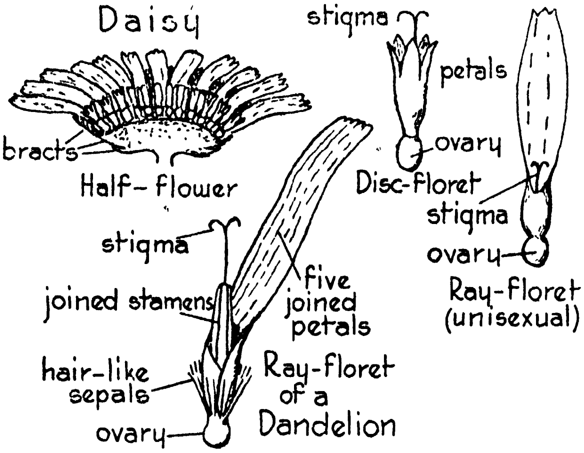

FIG. 112.—Composite flowers.

In general, insect-pollinated flowers have prominent corollas, which attract insects by their colour, perfume and the presence of *nectar*, a sugary liquid, often found in a special receptacle on the petal. Such a structure is a nectary.

In wind-pollinated flowers, chief among which are the grasses, there is no need for attractive structures. Such flowers are often inconspicuous, and the corollas may be absent.

The buttercup has five petals, sometimes more: but there is great variety in the number and shape of petals in different flowers. We shall see some of the range of structure later in this chapter (page 259). In some flowers the petals are joined together, and this is the basis of a system of classifying flowers into two groups—polypetallous, with free petals, and gamopetallous, with fused petals.

The *andrœcium* contains the male sexual cells and consists of a group of structures called *stamens*. Each of these has a stalk (the *filament*), and a head (the *anther*), which consists of two double *pollen-sacs* (Fig. 111; Plate III).

The stamens of all types of flowers show more similarity of structure than is found in other whorls; the main points of difference are in the relative sizes of anther and filament. In wind-pollinated flowers the anthers are often large and loosely pivoted on the top of the filament, so that the wind can toss them about and release the pollen. In some flowers the filaments of all the stamens are joined into a tube (lupin); while in others, such as the daisy and other composites, the filaments are free but the anthers are joined. Flowers with a tubular corolla may have the filaments fused to the corolla-tube (primrose, Fig. 113).

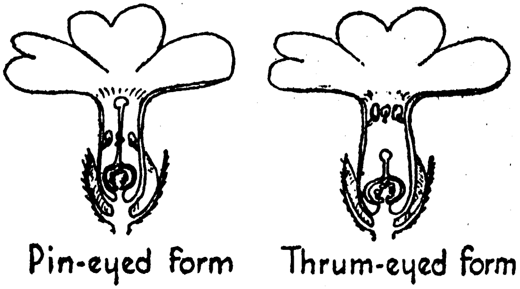

Fig. 113.—Primrose flowers.

The number of stamens in the buttercup is large and variable; but in more highly specialized flowers the number is simply related to the number of petals.

The male cells, when ripe, form a fine powder of *pollen-grains*, usually yellow, in the pollen-sacs. The structure of a pollen-grain is described below (Plate IV).

The *gynœcium* or pistil (Greek: pestle, from the shape of some of them), is, when present, always at the centre of the flower. There may be several separate structures called *carpels* (Greek;

fruits), as in the buttercup, or a single structure consisting of several fused carpels, as in the primrose.

Each carpel of the buttercup is a modified leaf, folded about its midrib, and enclosing an egg (*ovule*). Even in such a simple structure as the buttercup-carpel, three regions may be recognized—the *ovary* itself at the base, containing the ovule: the *stigma*, which is a sticky area at the top of the carpel, for catching grains of pollen; and the *style*, a stalk which connects the stigma with the ovary. In more specialized flowers these parts may be easily distinguished (Fig. 116). More will be said about the structure of the ovary when describing the process of fertilization below.

How to Examine and Draw Flowers.

In class you will be provided with flowers to examine and draw; but you should also pick flowers yourself for this purpose in your spare time. In doing so, take care not to uproot the flowers, nor to remove so many from one spot that the beauty of the place is spoiled. It is always more satisfactory to examine flowers where they grow if possible, so you should carry a hand-lens and a pencil and paper when in the country.

INQUIRY 120. When given a flower to examine, observe all you can about it before removing any of its parts. Note the number of parts in each whorl, counting them unless there are obviously more than ten, when they should be described as "many", or "indefinite".

Draw one sepal and one petal of a radial flower. If the flower is bilateral, draw one of each type of petal.

Cut the flower into two halves along an axis (*the* axis in a bilateral flower), and draw the appearance of the *section*, showing cut surfaces by double lines, and uncut edges by single ones (Fig. 111).

Make a *floral diagram* of the plan of the flower, showing the number and relative positions of the parts, but not their shapes (Fig. 114). Sepals are distinguished from petals as shown in the figure, and the conventional symbols for the flower-parts saves the trouble of labelling the diagram.

Dissect another flower of the same kind into pieces, and examine with a hand-lens. Draw any features of unusual structure.

INQUIRY 121. Take every opportunity of observing, in as many types of flower as possible, the features described. Do not neglect a flower because you do not know its name. That is easily learnt later; but you may never see that type of flower again. Whenever you inspect a flower, take a good look at its natural surroundings, and see if you find any relation between its structure and its environment. (Delicate flowers in sheltered places, wind-pollinated flowers exposed on tall stalks, or hanging on trees, etc.)

Pollination.

Before fertilization can take place (see below) the male reproductive cell, the pollen-grain, must be transferred from the andrœcium to the gynæcium. In some cases, this transfer, which is called *pollination*, takes place in a single flower; but this is rare, because several factors combine, for reasons which we shall discuss in Chapter XXII, to ensure that, where possible, the pollen from one flower shall reach the stigma of another flower of the same species. This is called *cross-pollination*.

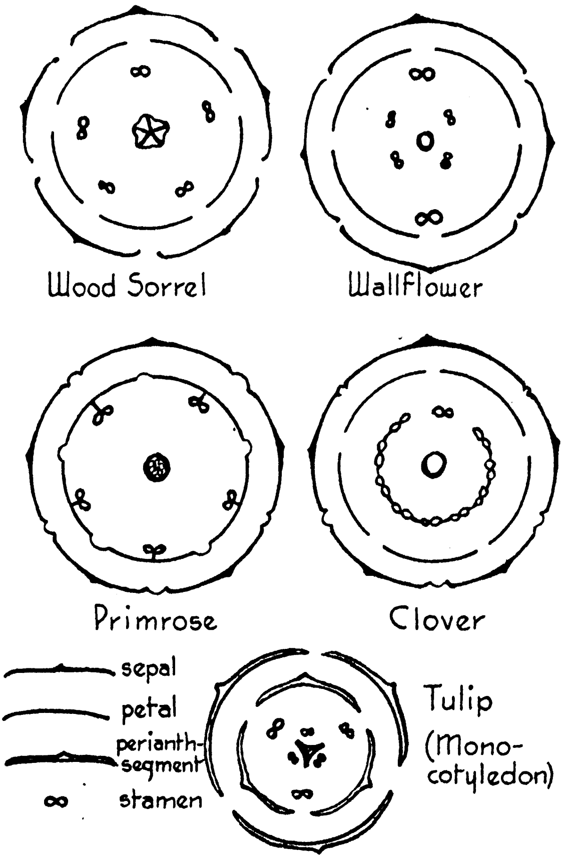

FIG. 114.—Floral diagrams.

Cross-pollination may be brought about in several ways. If in each flower the stamens and pistil ripen at different times, self-pollination is prevented; but since different flowers of the same species ripen at different times there will usually be a stigma ready to receive pollen from another flower.

This method succeeds without the need for any modification in the shape of the flower, and is commonly found in simple flowers like the buttercup and in wind-pollinated flowers.

An even more effective way of ensuring cross-pollination is to have only male, or only female, organs in any one flower. This method too involves little modification of shape; although if the unwanted organs are not simply absent, but are present and sterile, they may be modified to help in the work of the fertile organs. An example of this is seen in many composite flowers where, in the male flower, the style is present and acts as a piston which pushes out the ripe pollen from the cylinder of fused anthers.

Unisexual flowers are very common. Wind-pollinated trees provide many good examples (page 51). Unisexual flowers are diœcious (i.e. *two* needed for fertilization). Bisexual flowers are monœcious.

In some plants, although there is no obvious means of preventing self-pollination, it is found that the flower is self-sterile: that is, even if pollen from the stamens does reach the stigma of the same flower, it produces no effect. This is very common among edible-fruit plants such as currants, raspberries and strawberries, and some types of apple, plum and cherry. This explains why many people who have a single fruit-tree in the garden find that, although the flowers have both stamens and pistil, no fruit ever forms on the tree. It is because there is not another similar tree sufficiently near. The lupin (page 259) is another example of a self-sterile flower.

Other methods of achieving cross-pollination usually involve both modification in the shape of the flower and the co-operation of animals, usually insects. There is a bewildering variety of such arrangements, and we can examine only a few representative cases.

In the *Primrose* there are two types of flower, each of which is monœcious (Fig. 113). In one type the stamens are at the top of the corolla-tube, and the style reaches only half-way up. Thus a bee poking its proboscis (page 296) down the tube in search of nectar may collect pollen on different parts of its proboscis, according to the type of primrose. Pollen from a short-styled flower will be in the right position for transfer to the stigma of the next long-styled primrose visited, and vice versa.

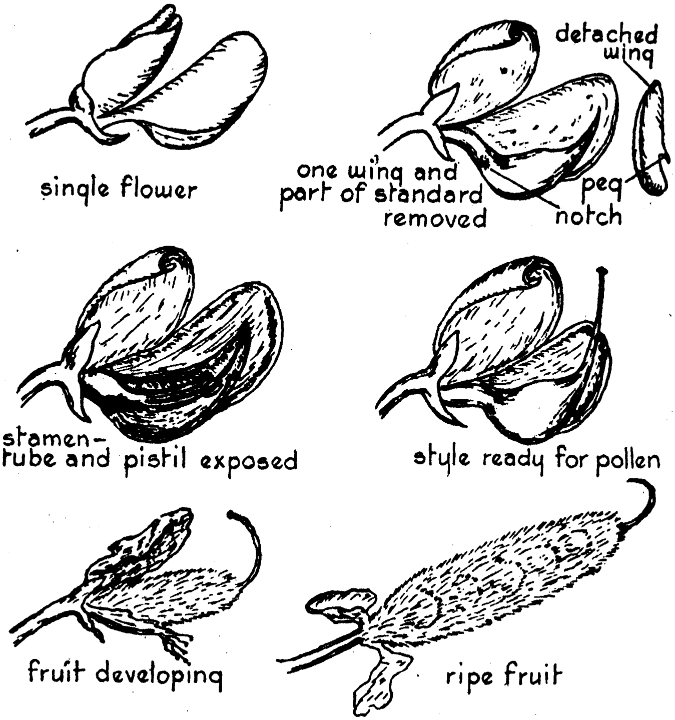

FIG. 115.—Lupin—flower and fruit.

In bilateral flowers there are often elaborate arrangements for pollination. Indeed, this often seems to be the only reason for their complicated shape. The *Lupin*, a member of the leguminous plants (pea family) is a good example. There is a large upright petal, the *standard*, a pair of side-petals (*wings*), and a pair of front petals joined together into a boat-shaped structure (*keel*), which hides and protects the stamens and pistil. Each wing-petal has on its inner side a peg which fits into a notch near the base of the keel. When a bee alights on the wings its

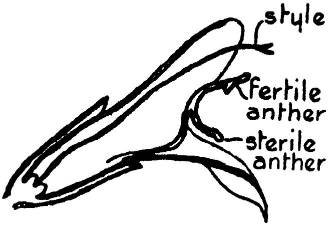

FIG. 116.—Section through flower of Garden Sage.

weight presses them down, and they in turn press down the keel. If the flower is in the stage when its anthers are ripe this process causes the stamens to push a little mass of pollen out through the tip of the keel on to the underside of the bee's body. If the bee next visits an older flower its style will be protruding through the tip of the keel, and will touch the pollen on the bee's body. The lupin produces no nectar, but many leguminous plants do (e.g. sweet-pea), and in their flowers, instead of all ten stamens being joined, the upper one is free, leaving room for the bee's tongue to probe down the tube for the nectar inside.

It will be seen that in the leguminosæ the style is surrounded by loose pollen as it lengthens. It is therefore necessary that the flowers should be self-sterile. In the broom, which belongs to the same family, the stamens are so tightly packed that when the insect alights the keel explodes, showering the bee with pollen. The process cannot be repeated.

The garden sage has only two stamens, and they are of peculiar shape. The lobes of the anther are separated by an unusually

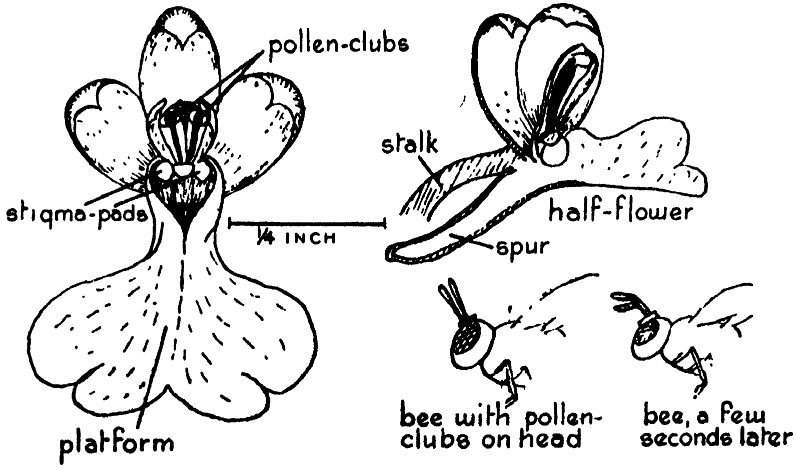

FIG. 117.—Pollination in an orchid (Early Purple Orchid).

long connective, which is hinged on the filament as seen in Fig. 116. The lower lobes are sterile, and act simply as triggers. When the bee pushes its head into the flower to reach the nectar at the base of the ovary it pushes back the sterile lobes. This brings the fertile lobes down smartly on the insect's back, leaving some pollen. When it visits an older flower the style, which has grown long and curved, touches this part of the bee's back and picks up the pollen.

Fertilization.

When the pollen reaches the stigma of a flower of the same species, the process of fertilization is ready to begin. The pollen-grain has two walls. The outer wall is thick and tough; but it has several soft spots on its surface, through which the thin inner wall protrudes. Inside the grain are two nuclei, called respectively the generative nuclues and the tube-nucleus.

The stigma secretes a sugary substance which induces the pollen-grain to grow. A tube grows out through one of the soft spots, and the tube-nucleus passes into its tip, followed by the generative nucleus. The tube forces its way down through the style, and while this is happening the generative nucleus divides in two.

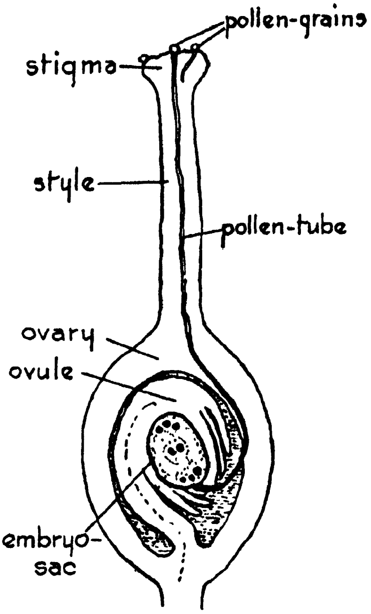

FIG. 118.—Fertilization of a flower.

The ovule has a small hole in it called the micropyle. The centre of the ovule is occupied by a large cell called the *embyrosac*. At the end of the cell opposite the micropyle are three nuclei forming a tissue which later will help to nourish the young embryo. At the end near the micropyle are three other nuclei, one of which is the *egg*. At the centre of the cell is a pair of nuclei which eventually fuse together forming the *central fusion-nucleus* (Fig. 118).

The pollen-tube grows in through the micropyle. This involves, in a long-styled flower, a considerable lengthening of the pollen-tube. The food needed for this growth is absorbed from the tissues of the style as the tube passes through it. The micropyle persists after fertilization and serves, in the ripe seed, as the hole through which water enters at germination (page 157).

When the tube enters the micropyle its tip breaks, and the tube-nucleus, its work finished, withers away. The two generative nuclei enter the embryo-sac. One of them fuses with the central fusion-nucleus, and this is the start of the formation of *endosperm*, a tissue which provides food for the early development of the *embryo*. The embryo starts its life as a new individual when the remaining generative nucleus fuses with the egg; this is the most important part of the fertilization-process. The wall of the ovule hardens into a protective case, called the testa. This, with its contents, constitutes the *seed*. The endosperm may all be used up before the seed is liberated, or it may persist and help to provide energy for germination. There are thus two types of seed, *endospermic* and *non-endospermic*. Both monocotyledons and dicotyledons include examples of both types. The bean and sunflower (Chapter XII) are non-endospermic dicotyledon seeds, while the castor-oil seed is endospermic. Most monocotyledon seeds are endospermic, but there are some non-endospermic groups, such as the orchids and water-plantains.

INQUIRY 122. Dab the stamens of various types of flowers on to microscope-slides and examine with low and high power. Note the geometrical shapes and the "sculpturing" or raised patterns on the surface of the pollen-grains. Try to find spots which appear more transparent than the rest of the grain. These are the thin areas referred to above.

INQUIRY 123. Shake a number of pollen-grains into sugar solution in a petri-dish or deep cavity-slide. Protect from dust and leave in a warm place for two hours. On examining under the microscope, some of the grains will be seen to have put out pollen-tubes, and the progress of their growth can be followed for some time. The rate of growth varies greatly in different flowers. In the hazel it may grow only at the rate of one millimetre a month, whereas in the crocus it grows about fifty millimetres in one day.

INQUIRY 124. Try pollinating an indoor flowering plant by transferring pollen with a small paint-brush. Compare the progress of treated flowers with others which you have left as a control. (Steps should be taken to exclude insects—hence the choice of an indoor plant.) Apply to some of the flowers pollen from plants of different species.

INQUIRY 125. Tie small muslin or silk bags round some of the flowers on a stem of lupin in the garden, just as they open. Leave some of the flowers as controls. Observe which flowers set seed.

Fruit.

The seed is contained, alone or with others, in the remains of the ovary. All the parts of the flower (mainly the ovary) which persist after fertilization constitute the *fruit*. This is the botanical meaning of the term, and is not quite the same as its common meaning. Thus, acorns, all kinds of nuts, peas in pods, and grains of wheat are all true fruits in the botanical sense; while strawberries, apples, and rose-hips are *false fruits*, because their fleshy portions develop, not from the flower, but from the top of the flower-stalk (i.e. from the receptacle).

In a true fruit, the ovary-wall develops into a tissue called the *pericarp* (Greek: fruit-case). In most fruits, dry or fleshy, this has two layers, the epicarp or outer layer and the mesocarp. In fleshy fruits like plums and cherries, which have stones, the stone is a third layer, the endocarp, which is hard and protective, so that even after the seeds are shed they do not germinate until this layer has been broken or rotted away.

Fruits are classified according to the nature of the fruit-case. The system is rather complicated, but its main features are as follows.

Dry Fruits.

These are of two types—*dehiscent* and *indehiscent*. Dehiscent (splitting) fruits open automatically. These include the *follicle*, *legume* and *capsule* described below. An indehiscent fruit liberates its seeds only after being broken open by violence or by the action of bacteria. The main types of indehiscent fruits are *achenes* and *nuts*.

Follicle: formed from a single carpel, opening by a single slit (marsh marigold, larkspur).

Legume: formed from a single carpel, but opening by a double split (pea).

Capsule: formed from an ovary consisting of several fused carpels. If there are only two carpels the capsule is called a siliqua, and opens by a double split, starting at the bottom. This leaves a partition to which the seeds are attached, and fall off a few at a time (wallflower).

There are many other types of capsule with various methods of opening, some of which are shown in Fig. 101.

Achene: formed from a single carpel, and having a tough but pliable pericarp (buttercup, dandelion).

Nut: formed from an ovary of fused carpels, but often only one seed develops. There is a brittle woody coat (acorn, hazel).

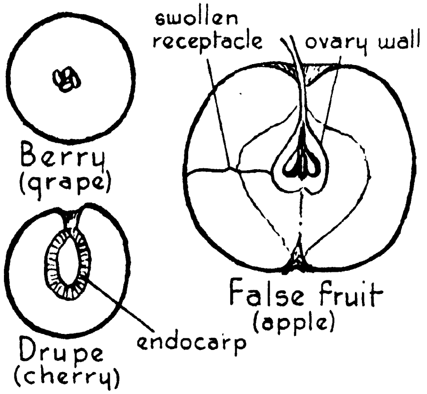

FIG. 119.—Fleshy fruits.

There is good reason for the fact that many-seeded fruits are usually dehiscent. It provides opportunity for the seeds to be scattered before they germinate, thus avoiding overcrowding of the seedlings.

Fleshy Fruits.

Fleshy (succulent) fruits are of two types—the *berry* and the *drupe*. Both are indehiscent, since the fleshy tissue provides food for animals, which can therefore be relied upon to liberate the seeds.

Berry. The pericarp is in two layers, the outer skin or epicarp, and the fleshy layer or mesocarp. There are usually several seeds in a berry. Examples are: mistletoe, gooseberry, grape, citrus-fruits, banana.

Drupe. The pericarp is in three layers, epicarp, fleshy mesocarp, and a hard stony inner layer, the *endocarp*. This protects the seed after the fruit has been eaten. A drupe seldom contains more than one seed, for the same reason as given above in connection with indihiscent dry fruits. Examples of drupes are plum, cherry, and other well-known "stone"-fruits.

It is worth noting that the common names of some fruits are botanically incorrect. Raspberries and blackberries are not berries, but collections of small drupes. The holly berry is not a berry, but a drupe. The date, in spite of its stone, is not a drupe, but a berry. The hard substance is not part of the epicarp, but is a mass of hard stony endosperm inside the seed. A thin testa separates it from the mesocarp. The coco-nut is not a nut, but a drupe. We usually see only the endocarp and its contents. The epicarp and mesocarp have been removed. The mesocarp is fibrous rather than fleshy, and from it the familiar coco-matting is made.

False Fruits.

The strawberry, apple, pear and rose-hip are examples of false fruits. The fleshy portions of these fruits are formed not from the ovary wall, but from the receptacle (page 252). The true fruit of the strawberry is the group of achenes (the "pips") scattered about the outer surface.

Fruit-Dispersal.

It should not be difficult to judge the means by which many of the fruits described above are dispersed. Fleshy fruits are obviously made for dispersal by animals, and often possess, in addition to their food-value, attractive colours and fragrance. The seeds may be discarded by the animal (mistletoe, page 209), or may pass through its alimentary canal unharmed, thanks to the protective testa or, in the case of drupes, the stone.

Many dry fruits also are dispersed by animals. Thus, although the seed in a nut is destroyed if eaten, many animals (squirrels, etc.) carry nuts about and do not eat them all: the ones which escape notice are thus dispersed. Many fruits become entangled in the coats of animals and some, like cleavers, most grasses, burr-marigolds, etc., develop special hooks or rough surfaces which make the process more efficient. If a man has walked through a field during the summer the turn-ups of his trousers will often reveal evidence of the fact in the shape of grass-fruits, etc. Wading birds often carry seeds and fruits in the mud on their feet.

Dry fruits are, however, more commonly dispersed by wind. In this case, the shape of the fruit, usually an achene, may be modified to help it to float in the breeze. The sycamore and ash have paired winged achenes. The achene of the dandelion has a parachute of hairs, called a pappus, formed from modified sepals. The clematis (old man's beard) has a long feathery "plume" on its achene, formed from the remains of the style.

Water-dispersal is rare in this country, an example being the water-lily (page 33). In tropical countries, coco-nut palms overhang the water of lagoons or the ocean; the fruit falls into the water and is washed along the shore by currents, until it either becomes waterlogged and sinks, or is cast up again on dry land.

Seed-Dispersal.

Apart from the dispersal of the entire fruit, there is often provision for the dispersal of individual seeds, in the case of dehiscent fruits. Thus the willow-herb has a pappus on each seed; the seeds of conifers have wings (page 53).

The seeds of violets, bluebells, gorse and broom have coloured "oil-bodies", or "arils", which are said to attract the attention of ants or insects.

All wind-dispersed seeds are specially modified in composition if not in shape, for they contain a high proportion of oil (which is lighter, for its volume, than carbohydrate), and are very dry. These two factors help them to float in the wind.

INQUIRY 126. Take every opportunity of examining fruits, and of dissecting them and examining their parts.

QUESTIONS

SECTION A.

1. Choose a common flower, name its parts, and describe the function of each.

2 & 3. Name and describe one example of each of the following: (*a*) a flower containing all four whorls; (*b*) a flower which has no sepals; (*c*) a flower which has no petals; (*d*) a monœcious flower; (*e*) a diœcious flower; (*f*) a radial flower; (*g*) a bilateral flower; (*h*) a composite flower. Choose a different flower in each case.

4. Draw a sectional diagram and a floral diagram of (*f*) and (*g*) above.

5. Draw sectional and floral diagrams of single flowers of each type to be found in the head of a composite flower, giving its name.

6. Draw and describe, giving the name in each case, (*a*) a dry dehiscent fruit, and (*b*) a dry indehiscent fruit. Describe in each case the method of dispersal.

7. Draw and describe, giving the name in each case, (*a*) a berry, and (*b*) a drupe.

8. Describe the process of pollination in a named insect-pollinated bilateral flower.

SECTION B.

1. What are the advantages of cross-pollination in flowers?
2. Describe the process of fertilization in a flower, paying special attention to the nuclear fusions which occur.
3. Write an essay on the relations between flowers and animals.
4. Write a short essay on "The economic importance of flowers".

CHAPTER XXI

EXCRETION AND REPRODUCTION IN MAMMALS

WASTE matter is eliminated by mammals in several ways. Waste gases are given off through the skin and from the lungs. A considerable amount of water-vapour is present in the expired breath, as may easily be shown by breathing on a cold pane of glass. Waste solids are expelled, along with small amounts of water, from the rectum. A great deal of moisture, with a little dissolved solid, leaves the body as sweat through the skin.

These three processes are not sufficient to dispose of all the surplus water which accumulates in the body, and the remainder is expelled as *urine* through the urinary or renal system (Greek: *renes*, kidneys).

Perspiration.

Perspiration is the Latin word for the English word "sweat".

Sweat is salt solution, containing in addition small amounts of other break-down products of food and tissues. It is collected from the blood by the sweat-glands (Fig. 58), (of which an average adult human body has more than two millions), situated chiefly in the palms, soles and armpits, but also found all over the body-surface. The main function of sweating is to control the body-temperature (page 81), and its excretory value is only secondary.

The Renal System.

The decomposition-products of carbohydrates and fats are carbon dioxide and water, which can be excreted mainly by the lungs and skin. Proteins contain nitrogen. If they are used for building tissues, the nitrogen is incorporated in the new tissues; but if they are used as sources of energy, the nitrogen, being of no use as fuel, is removed in the form of ammonium compounds.

Similarly the nitrogen in worn-out tissues is also turned into ammonium compounds. These compounds are poisonous in large quantities, so the living cells act on them in a way which converts them into a harmless substance, *urea*. All living cells can do this, but the *liver* does it on a large scale, as one of its main functions. The urea is passed on, dissolved in the blood, to the kidneys, a pair of dark-red organs attached to the dorsal body-wall.

A *kidney* is a compact tissue consisting of a mass of coiled tubes which all feed into a drainage-tube called a *ureter*, which connects the kidney with a muscular bag called the *bladder*. Each kidney has an artery and a vein which connect it directly to the aorta and the postcaval vein (page 141). All the blood in the body passes, at regular intervals, through the kidneys (page 131).

As the blood passes through them, the kidneys remove from it the urea and a large quantity of water. The solution, called *urine*, passes into the bladder where it accumulates. The bladder empties to the exterior through a tube called the *urethra*, which is controlled by a voluntary sphincter muscle (page 131).

You should now understand why, as stated on page 82, it would not be a good thing to feed exclusively on proteins, even though they provide both energy and body-building materials; the strain on the excretory system would be too great. Indeed, in days when some people could eat large amounts of meat and other rich protein-foods, kidney troubles were very prevalent.

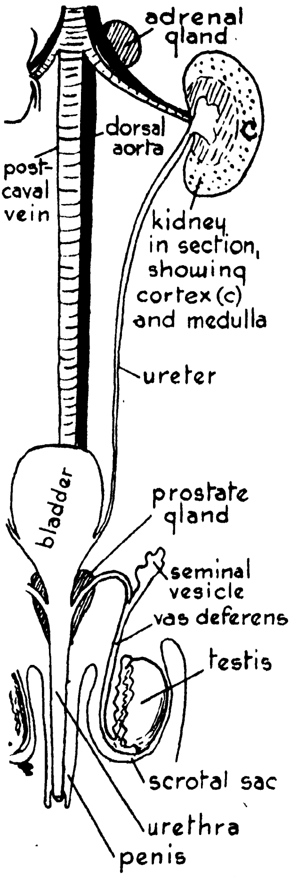

FIG. 120.—Renal and reproductive organs of Male Rabbit.

Near the kidneys are the adrenal glands (page 132). In human beings they are actually on top of the kidneys, and are called supra-renal glands.

Reproduction in Mammals.

In describing the reproduction of the frog it was said that the female sheds eggs into the water and the male scatters over them the male cells, or sperm. Fertilization in the frog is thus *external. In mammals, fertilization is internal;* the sperms are injected by the male into the female's body, where they come into contact with the eggs. There is thus a far better chance of each egg being fertilized. As might be expected, one result of this is that mammals produce very few eggs in comparison with lower animals. The male mammal also produces fewer sperms, though the number is still enormous, amounting to many millions in a lifetime.

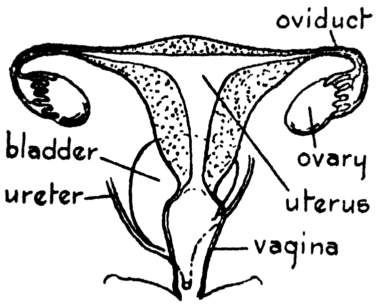

FIG. 121.—Reproductive organs of Female Rabbit.

Male Reproductive Organs.

The sperms develop in a pair of testes (singular, testis), each situated in a scrotal sac. From the testes the sperms are carried by a tube called the *vas deferens* (Latin: pipe-line) to a storage-organ, the *seminal vesicle*, situated just below the bladder. The sperms are suspended in a fluid secreted by two glands, the *prostate gland* and *Cowper's gland.* A tube connects each seminal vesicle to the urethra, through which the seminal fluid, carrying the sperms, travels when it is to be used. The sperms are mobile and swim about in the fluid. Fig. 120 shows diagrammatically the sex organs of a male rabbit.

Female Reproductive Organs.

Eggs are formed in a pair of *ovaries* and shed into the body-cavity, from which they are collected by the funnel-shaped ends of the *oviducts*. Here they stay for some time and if, during that *period*, they are not fertilized by sperm, they finally pass out of the body through the urinary aperture and die.

If sperms are introduced into the female's body, they swim into the oviducts and fertilize the eggs. A single sperm fuses with each egg which then passes from the oviduct to the womb or *uterus*, and becomes embedded in its wall. It then immediately begins to develop into an embryo. Fig. 121 shows diagrammatically the female sex organs of a rabbit.

Development of Embryo.

The embryo quickly develops a network of blood-vessels, which spreads over the wall of the uterus, and absorbs food and oxygen from a similar network belonging to the mother. Waste products are passed into the mother's blood through the same system. The heart and brain are the first organs to develop.

At a stage of development which varies slightly with different mammals, the young animal is freed from its mother's body by powerful contractions of her muscles: its lungs come into action, and its senses gradually begin to operate independently. It is still wholly dependent on its mother, however, for its food.

The time between fertilization and birth varies widely in different mammals, but is fairly constant for any one species. It is called the period of gestation (Latin: carrying). In the rabbit it is thirty days; in the dog, two months; in human beings, nine months; and in horses, eleven months. There is no obvious relation between the length of the gestation-period in different animals, and the stage of development reached by them at the time of birth.

Early Development After Birth.

Mammals, when born, are very helpless compared with lower animals: and the parents, especially the mother, are fully occupied for some time in caring for the offspring. Many young animals are constantly carried about by their mother for some time after birth. An extreme case of this is the kangaroo, which is only about an inch long at birth and is carried in a pouch on the mother's body. The koala-bear (Teddy-bear) carries its young on its back. Young bats and monkeys cling to their mothers' fur. Human babies do not cling in this way, but a new-born baby can support its weight when hanging only by its hands. This is sometimes observed when a mother tries to put a very young baby down and it clings to her dress.

The time taken for young mammals to "find their feet" varies considerably. A foal (young horse) can stand, though shakily, within a few minutes of being born; whereas a baby is about nine months old before it can stand unaided.

Many young mammals are blind at birth: this is well known in the case of puppies and kittens. Babies are not blind but, lacking experience in the use of their eyes, they cannot usually focus them on an object until they are a few weeks old.

Parental Care.

Parental care is not confined to mammals: though it is more widespread among them than among other animals. Birds are well known for their care of their offspring (page 307). The cuckoo is exceptional in taking no interest in its young. It lays its eggs in the nests of other birds which rear the stranger with their own brood.

Many animals are fierce in the defence of their families. Thus the mildest of domestic cats may revert to the violent habits of its relative, the tiger, if its kittens are threatened.

In general, parental care increases as we pass from lower to higher types of animals; but there are exceptions, of which the small fish known as the stickleback is an example. In this case, however, it is the male parent which looks after the offspring. Many exceptions to the rule also occur among the insects. The sisyphus beetle takes great pains to look after its offspring: and here again it is the male which does the work. A fascinating account of the life-story of this and many other insects was written by the famous French naturalist, J. H. Fabre, in his book *Social Life in the Insect World* (1911). You should try to read this book which is probably in your school library.

> INQUIRY 127. The reproductive systems of male and female rabbits will be shown as demonstration dissections or permanent mounts. You should learn all you can about the social life of animals.

In the next chapter a general review of reproduction is given, and many references to the topic will be found in other chapters.

QUESTIONS

SECTION A.

1. Describe in outline the means by which excretion is carried out in a mammal, stating the special features of each method.
2. Compare excretion in (*a*) amœba, (*b*) earthworm, and (*c*) the rabbit.
3. Make a labelled diagram of the renal system of the rabbit, and write short notes on the functions of the parts.
4. Make a list of the advantages and disadvantages experienced by a rabbit, from the time of conception (fertilization) to the time when it can feed on grass, compared with a frog during the period from hatching to the internal-gill stage of the tadpole.
5. Compare the reproductive organs of the rabbit with those of the earthworm.
6. Suggest why the heart and brain are the first organs to develop in a mammalian embryo. In what order of development (giving reasons) would you place the following organs? Spinal cord, ears, limbs, excretory organs?
7. Describe instances which you have observed of parental care shown by a (named) domestic animal.
8. Write a short account, in diary form, of the first year in the life of a baby.

SECTION B.

1. What do you think is the purpose of the period of gestation in mammals? Why is it hardly ever found in lower animals?
2. What are the advantages of internal fertilization in mammals? In what other group of animals is it usual, and what is the connection in their environment which explains why they should have the same kind of fertilization as the mammals?
3. Suggest reasons why development after birth should seem so slow in humans as compared with, say, horses or cattle.
4. Compare the extent of parental care, if any, shown by three of these animals, hydra, earthworm, bee, stickleback, frog, thrush, bat, rabbit.

CHAPTER XXII

HEREDITY AND ANCESTRY

THE fact that the characteristics of an organism depend to a large extent on those of its parents and ancestors is well known, as is shown by the common expressions "family resemblance", "like father like son", "thorough-bred", "half-caste", etc. Many of the traditions about this fact have no scientific foundation and, about a century ago, Gregor Mendel, an Austrian monk, set out to discover the facts of *heredity*, the process by which characteristics are handed on from parents to offspring. His work is a perfect example of scientific investigation, and to understand how well he did it you must know something of the principles of scientific investigation in general.

Scientific Investigation.

The aim of scientific investigation is to discover both the general outline and much of the detail of the pattern into which all created things and events fit. Its methods involve two rather different, but equally important, processes which are usually carried on at the same time. One is the *ascertaining of facts*, or the collection of evidence. The other is the explanation or *interpretation of facts* already collected. The whole operation is in some ways like solving a jigsaw puzzle. All the pieces are there, but there are so many of them that it is impossible to keep them all in sight at once, and many of them have not even been turned over.

The first process mentioned above is like collecting all the pieces together, turning them over and counting them. Unfortunately the scientists do not know just how many pieces there are, so they cannot be absolutely sure that they have all the pieces needed for even a small part of the pattern until they have fitted them together. This explains why it is not possible to collect all the facts first, and then start building up the pattern. The two processes have to go on at the same time.

You will know that when part of a jigsaw has been completed it is often possible to make a shrewd guess at the appearance which some of the missing parts will show when they are found. The same applies in scientific investigation, and the guess is called a theory. Notice that, as in the puzzle, the theory is based on fact—there must be some existing evidence on which it can be built up. Further investigation may prove it correct, or incorrect. If the pieces are permanently lost it cannot be either proved or disproved absolutely; but the surrounding pattern of facts may be so clear that there is no reasonable doubt about the nature of the lost pieces.

When a fair-sized area of the puzzle has been completed, the picture it presents can be appreciated or interpreted and becomes one of the *laws of science*. So long as all further discoveries fit in with the law, it is accepted as a true statement of that part of the pattern. Suppose, however, that just one fact is discovered and proved: and this fact does not fit in with the law. Then the law has to be modified or abandoned as false, and a fresh start is then made to rearrange the facts properly.

Heredity and Mendel.

Mendel realized that the problem of heredity was so vast that it could only be tackled by concentrating on a few aspects of it at a time, and eliminating as many other factors as possible. Of all the organisms available, he must choose that which would provide the most information in the shortest time, with the least need for apparatus and interference with the natural life of the organism. He found that the organism which best suited his needs was the common edible pea. This plant is easily and quickly grown, easily self-pollinated, and protected from "foreign" pollen. Varieties of it were known which would produce almost identical plants through many generations—that is, they were *pure strains*. The seeds were big enough to be handled and examined. There were several features of the plants which were easily compared by rapid observation—for example, the colour of the unripe pods, the height of the whole plant, the colour of the seed-coat, etc.

Mendel's Experiments. Considering only one pair of characters at a time (such as tallness and shortness of plant), he selected plants which were known to "breed true" as far as this character was concerned, and crossed tall plants with short by artificially transferring pollen from one to the stigmas of the other. He found that the offspring were all tall.

Next, he self-pollinated the offspring, and found that, of the next generation, three-quarters were tall plants, and one quarter short. When the plants of this generation were self-pollinated all the short plants produced only short plants, while of the tall plants one-third gave only tall plants and continued like the dwarf plants to give the same kind through any number of generations; but the other two-thirds gave one short plant for every three tall, like their grandparents.

All this may seem a jumble of figures, but Mendel found a simple explanation for them. His explanation is summed up in several *Laws of Inheritance*, of which the most important are described below.

Law of Independent Characters. The make-up of an organism is the result of a large number of features ("*characters*"). These characters exist in pairs as, for instance, tallness and shortness, blue eyes and brown eyes, black hair and white (or colourless) hair, yellow pods and green pods: and any one individual can exhibit only one character from each of these pairs.

Law of Segregation. Each character has, corresponding to it, a *factor* or *determiner*; but for the character to appear in the individual, *two* factors must be present. These two factors may both correspond to the character which appears, or one may be the factor of the opposite character. Therefore, although only one character from each pair appears in an individual, the other character may be present in a hidden (*recessive*) form. Although all the normal cells of the individual contain two factors for each character, the reproductive cells (gametes), contain only one factor per character, so that when they fuse, the normal number is restored in the zygote, one factor having come from each pair. Thus, each factor-pair is split up (segregated) in the gametes, and new pairs are made up in the zygote. This explains how factors for opposite characters may come to be in one individual.

Law of Dominance. Mendel claimed that, in every pair of characters, one was *dominant* and one recessive. This means that if a factor-pair contains even only one factor of the dominant character, the individual will show only that character; the recessive character, if present, will not appear at all in the individual's make-up. Nevertheless, when the factor-pairs segregate in the reproductive cells, one-half of the gametes will have the recessive factor. If both members of a factor-pair are dominants, every gamete will contain a dominant factor only; while if both factors are recessives, every gamete will contain only a recessive factor.

In a plant which is a pure strain for a particular character, each cell contains two factors for that character, and if self-fertilized the plant gives rise only to the same arrangement of factors. Thus, a pure-strain tall pea-plant contains two factors for tallness. These are dominants. A pure-strain short pea-plant contains two factors for shortness. These are recessives.

An organism which contains one dominant and one recessive factor for a particular character is a *hybrid* for that character. It will be indistinguishable to normal observation, from a plant containing two dominants for that character. Now we see why, out of the tall offspring of self-pollinated hybrid peas, one-third behaved differently from the others. The one-third were pure strains, while the other two-thirds were hybrids like their parents.

Mendel's Ratio. The above laws apply equally to animals. Let us take an example. A guinea-pig's fur may be either black or white (pair of characters, black being dominant). Let us call the factor for blackness B, and that for whiteness (or non-blackness) b. Then a guinea-pig's body cells must all have one, and one only of the following combinations: BB, Bb, bB or bb. The two arrangements Bb and bB are identical. They are hybrids, while the others are pure strains. BB, Bb, and bB guinea-pigs are black, and bb ones are white. If two BB or two bb guinea-pigs are mated, the offspring must also be pure strains, since only one kind of factor is involved in each case. If, however, a pure black (BB) is mated with a pure white (bb), all four possible combinations of factors can arise again, so the offspring will include BB, Bb, bB and bb. That is, they will be in the *ratio*

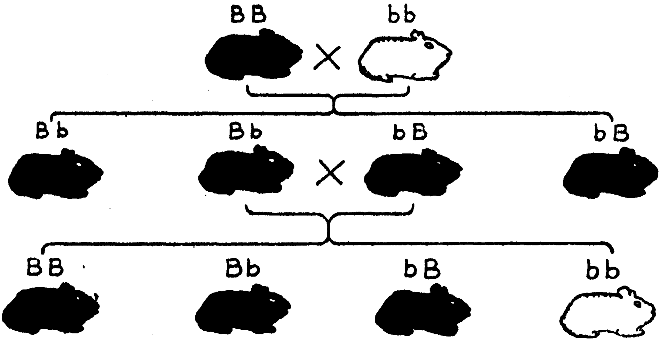

FIG. 122.—Mendelian Inheritance.

of three black *to one* white. This 3 : 1 ratio is called *Mendel's ratio.* Remember that the three can be further split up into one pure strain and two hybrids. These facts are shown in Fig. 122.

Reduction-Division.

On page 149 it was said that each cell of a particular species of organism always has the same number of chromosomes, and the steps were described, by which the characteristics of the individual are preserved during normal cell-division. Reproductive cells are formed by a different type of division; for if the gametes were each to have the full number of chromosomes, when they fused the number would be doubled in the zygote, and in every generation the number would be redoubled. To prevent this a special type of cell-division occurs; in animals it takes place at the division which results in the formation of the gametes themselves. In plants it may occur at some other stage in the life-history, but it still affects the gametes.

In reduction-division, as it is called, instead of the chromosomes splitting lengthwise (Fig. 83), one of each pair of chromosomes travels to one end of the cell, while the other member of the pair travels to the opposite end. Thus the resulting daughter-nuclei, though very similar, are not identical, and each contains only half as many chromosomes as the cell from which it came. When two such cells from different organisms fuse at reproduction, the original number of chromosomes is restored; the offspring has the same number of chromosomes as its parents, but half its chromosomes come from each parent.

All this must suggest to you that there may be a connection between the chromosomes and Mendel's "characters". Chromosomes and characters occur in pairs, are handed down as units, are segregated in the reproductive cells and reunited in the zygote. Since Mendel's death it has been shown that hereditary characters are in fact situated on the chromosomes. Each chromosome carries many factors, called *genes* (Greek: formers). Their positions on the chromosomes can be mapped out like beads on a string. These modern discoveries pay a fine tribute to the work of Mendel, who discovered so much about things of whose existence he was sure, but which, through being so far ahead of technical development, he could not inspect for himself. This is an example of discovery confirming theory, which in turn was based on observation and experiment. Mendel deduced his laws from observation of complete organisms: modern scientists can watch the handing-on of characters in the cells during reduction-division.

Reduction-division is responsible for the main advantages of sexual reproduction over asexual. It causes a reshuffling and redistribution of characters, and this keeps the species in a thriving condition. It also opens the way for change and adaptation in the species. Some of the possible combinations will be an improvement, some a deterioration, compared with the arrangement in the parent. Inferior combinations will be less able to cope with the environment and so liable to die out. As we have seen, reduction-division ensures that an offspring cannot be exactly like either of its parents in every detail, because half its chromosomes comes from each parent. Identity could be achieved only if both parents were pure strains for every one of the thousands of characters, and this is mathematically almost impossible.

Mendel completed his work in 1866, but it was neglected until 1900. He died in 1884 at the age of sixty-two.

Practical Value of Mendelism.

The example quoted above takes into account only one pair of characters; but it must be remembered that there are thousands of different characters in an organism, all obeying the laws of inheritance. There are many complications we have not time to consider in detail. One which may have occurred to you is that, if there are several characters on one chromosome, it cannot be true that they are quite independent: they must be linked together. This is so: and, moreover, chromosomes sometimes become entangled, and when they separate again, parts of them have been mutually exchanged. This further complicates the process of inheritance. Sometimes, dominance is not complete, and hybrids present an appearance midway between that of the two pure strains. Thus, the offspring of a cross between a pure red snapdragon and a pure white will be pink, because the dominance of red over white is imperfect. The offspring of self-pollinated hybrids in this case will be in the proportion: one red, two pink, and one white. This bears out Mendel's explanation of the examples given above.

In spite of difficulties a tremendous amount of knowledge has been acquired about inheritance during the last fifty years, and is put to good use, especially in the breeding of plants and animals for the use of mankind.

Thus, by selection and combination of suitable factors, the quality of cattle for the production of beef and milk is being constantly improved. Potatoes are being bred which carry factors making them immune to blight. New colours and shapes of flowers are produced by gardeners. Knowledge of heredity makes it possible to do all this fairly quickly, and without producing a high proportion of useless stock, as was done when breeding had to be done by "trial and error".

Some scientists have advocated the application of this knowledge to the scientific improvement of human beings. There are several obstacles to this. In the first place, human beings are so intermarried that it is hardly possible to distinguish pure strains except in unimportant characters such as eye-colour. Secondly, the average human family has so few members that a very large number of families would have to be included in any experiment before the mathematical possibilities could be realized (for instance, if there are only two children in a family, characters cannot appear in the ratio 3 : 1). Thirdly, the success of any scheme of selection depends largely on the rejection of unsuitable specimens, and this cannot be done with human beings, whose souls are of equal value, whatever their biological make-up. Finally, when human beings choose marriage-partners, biological factors are, quite rightly, not the only, or even the main, determinants. Spiritual, social and economic factors also play a big part. Attempts to confine selection to biological grounds could not succeed without compulsion, and this would be unjust.

Nevertheless, Mendelism is of value in connection with human inheritance in some cases: for example, it has become possible to discover whether or not persons must expect to be subject to certain ailments, just because their parents or other relatives suffered from them. Most of the ailments which have been shown to be inherited are rather uncommon, such as hæmophilia (uncontrollable bleeding), brachydactly (shortness of fingers), etc.

Review of Reproduction.

In various chapters we have met different types of reproduction, and it will be convenient to review and compare them. There are two main types of reproduction, asexual and sexual. There is much wider range of method in asexual reproduction, and it is often closely bound up with environment. In amœba, for instance, asexual reproduction occurs when conditions are good and food is plentiful, so that there is no need for special means of dispersing the offspring. In general, it may be said that asexual reproduction is the means normally employed for *colonizing* a given area up to the limit of its power to support a particular type of organism. Many examples have been given: hydra (budding); yeast (budding); Solomon's seal (breaking-up of rhizome); potato (tubers); mucor (spores).

Sometimes, as in the case of mucor, asexual reproduction results not only in colonization of the immediate surroundings, but also in the production of resistant spores which enable the organism to be widely dispersed.

Asexual reproduction, or vegetative propagation, may be of use in the artificial multiplication of organisms, as in the case of seed potatoes, and in budding and grafting.

The great handicap of asexual reproduction is that there is no chance of new combinations of hereditary factors being introduced, so the "old formula" has to be used over and over: and if the environment alters, the organism may be unable to cope with the change and be driven out of existence, or reduced to a very small range of distribution.

Sexual reproduction on the other hand allows of reshuffling of characters to an almost unlimited extent; so that if the environment changes there will be a good chance of some combination of characters enabling the organism to cope with it, even if all the specimens with other combinations die off. Thus the successful combination of characters ensures the survival of the species.

The fundamentals of sexual reproduction are the same wherever it occurs in the whole range of living things (page 198). The main differences are in the detailed structure of the sex-apparatus; and even here there is remarkable uniformity among animals and, along other lines, among plants. Note, for example, how it has been found possible to give almost the same names to the sexual organs of earthworms, insects (page 292) and rabbits. The sperm-cells of all animals, from hydra to Man, are very much alike: and at an early stage of development the embryos of all vertebrates are so similar that only an expert could distinguish them.

This last fact led a nineteenth-century biologist, Haeckel, to use fraudulent methods in an attempt to persuade people to accept a theory. He was so convinced that all vertebrates had a common origin that he drew a series of diagrams of the embryos of different types of vertebrates: and to make their resemblance more striking he slightly altered the proportions of several of the diagrams, making them more nearly alike. This is unforgivable in a scientist and has cast doubts on all his work, much of which is no doubt reliable.

Constancy of Species.

You were reminded on page 148 that elaborate precautions are taken during cell-division to preserve the individual characteristics of the organism. When vegetative reproduction occurs, therefore, it follows that, if the same process of cell-division gives rise to the new individual, it will start life with the same characteristics as its parent. Any differences which appear later will not be fundamental, but simply the result of response to differences in the environment. Since organisms of the same species can survive only in environments which are similar, it is unlikely that the offspring will depart greatly from the species pattern.

In some cases, remarkable superficial differences arise through changed environment. Thus, on high exposed mountain-tops, dwarf forms of trees are often found which, if transferred to the shelter of plains, grow to normal size. At the present time, the average size and weight of boys who work in cotton factories are noticeably less than of public-school boys of the same age. Such differences are not inherited, and always tend to disappear in the offspring if these are reared in a normal environment.

A biologist of the last century, named *Lamarck*, claimed that all the different forms of life on earth had developed from one, or a few, original forms, by the *inheritance of acquired characteristics*. Acquired characteristics are those, such as have just been described, which are acquired as a result of responding to some peculiarity in the environment. No one has ever proved in any particular case that acquired characteristics are passed on in the chromosomes from an organism to its offspring, though claims to have done so are often made. A recent one, which up to now has not been disproved, concerns a particular type of moth. In the country this moth is light-coloured, while in smoky towns it is dark-coloured. The investigators claim to have proved that the offspring of the dark-coloured form are themselves dark-coloured, even when reared in a perfectly clean atmosphere. This may of course be quite true, but it has still to be proved that the appearance of the dark colouring in towns is really an acquired characteristic, and not due to some other cause in which the atmosphere of towns plays no part. This is an example of the care which must be taken in establishing laws from evidence.

Origin of Species.

You may wonder, after the emphasis which has been placed on the constancy of species, how the innumerable species of organisms on the earth have arisen. If species were absolutely constant there could only be as many species on the earth as were separately created by God.

Although God can do all things, and the separate creation of millions of species would present no difficulty to Him, many species are so much alike that men began to wonder whether it were not likely that this great diversity had in fact arisen from a small number of types, which in the course of time have differentiated somehow into other types. To many people gradual development, or *evolution*, is more attractive and mentally satisfying than a large mass of apparently unconnected facts. Man likes to detect a rhythm in nature. If the task of filling the world with creatures had been given to human beings, they would most likely have started with a few kinds and gradually modified them in different ways until they had millions of kinds.

It does not necessarily follow that the mind of God works in the same way; so it is a waste of time to say that "evolution of species must have occurred because that is the more sensible way of doing things". What we must do is examine the evidence and try to find out what God did—not what we think He should have done.

The Evidence.

Embryology. It has already been said that in their early stages the embryos of vertebrates are very much alike. This *may* mean that they come from a common ancestor; but note carefully that it does not by itself *prove* that they did. If you see two copies of a daily newspaper they are so much alike that it is reasonable to suppose that they were printed by the same machine; but in fact one may have been printed in Manchester and the other in

London. Close similarity suggests, but does not prove, a common origin.

Homologous organs. The limbs of all vertebrates except the fishes are built on a common plan. Even when they seem very dissimilar from the normal appearance (e.g. the flipper of a whale, the wing of a bat), the skeleton is still recognizable from the general pentadactyl plan. This again suggests that the different types of vertebrate may have come from a common ancestor.

Vestigial organs. Many higher animals possess organs which are of no apparent use to them, but obviously represent organs which in lower animals are of great use. An example is the muscles which enable some people to waggle their ears. Others are the vermiform appendix in Man, and the totally enclosed, internal legs in some snakes, which can make no use of them. It is argued that such organs are relics of the time when the organism belonged to a lower group of vertebrates.

The fossil record. The strongest evidence in favour of evolution is the fact that in certain places, where successive layers of rock have been laid down throughout the ages, vertical excavations bring to light fossils (skeletons which have been converted into stone) which become obviously more primitive as greater depths are reached.

The most famous example is the fossil history of the horse, as discovered by excavations in the western United States of America. As explained on page 123, the modern horse has only one toe on each foot, with splints which represent the second and fourth toes. In America, at successive depths, fossil horses have been found with three toes, only one of which touched the ground; then three toes, all touching the ground; then three toes with splints of the other two; and finally four toes. This obviously suggests that the horse began with a five-toed limb, and gradually changed to its present form. The size of the animal has also progressively increased, and the shapes of its teeth have become more specialized.

It should be noted that the story of the horse only covers changes in the appearance of the horse. It does not explain how the horse came to be a horse.

Another aspect of the fossil record is the fact that below a certain depth (Triassic rocks) no mammalian fossils whatever have been found, although fossils of reptiles are plentiful. This is really strong evidence that mammals are the latest types of life to appear on the earth; though once more it must be noted that this in itself does not prove that they were developed from reptiles.

Island forms. It is often found that on islands which were separated from the mainland at some time which can be ascertained by geologists, primitive forms of life are found which are extinct on the mainland. In Australia and New Zealand, for example, the kangaroo and the platypus, two primitive types of mammal are found, as well as a primitive kind of lizard, the tuatara.

These facts are explained by assuming that on the mainland these forms were destroyed by later and more advanced forms; but that on the islands they were cut off from the general evolutionary advance, and so spared from extinction.

To sum up, the choice is broadly between special creation and evolution. Separate creation must have occurred if evolution has not; special creation may have occurred in any of several ways, but most likely (from fossil evidence) by a series of "waves", separated by long periods of time. Evolution supposes one, or a few, original forms of life, from which the others have developed, not in one long string, but rather like the branching of a tree, arising at different levels in the passage of time.

Note that, whichever is the true account, it still demands both creation and active continuous maintenance by the Creator; so far as the activity of God is concerned there is little to choose between them.

There is not at present enough evidence to prove the theory of evolution. It is certain that some "evidence" has been falsified by people who already accepted the theory and wished to impose it on the world (e.g. some fossils which do not fit in well with the theory have been suppressed, while others which do have been given undue publicity. See also page 282). The fact remains, however, that the theory explains many facts in a reasonable way. Both theories have their supporters among brilliant and honest scientists, and you are free to adopt either, or consider it an open question. Many examining bodies, however, require candidates to be able to give the evidence for evolution in broad outline.

The Mechanism of Evolution.

You should note that in stating the evidence for evolution, no explanation was offered of how (assuming evolution to have occurred) the changes were brought about. This is a separate problem, and just as far from an agreed solution as the main one. Lamarck's theory has been referred to above.

Darwin's theory was that new species arose by *Natural Selection*, in which the most important factor was the *Struggle for Existence*. His arguments were published in 1859 in a famous book, *The Origin of Species* (revised edition published in 1900 by Messrs. John Murray).

Darwin claimed that there always exist more organisms in any environment than the environment can support: that they therefore struggle for existence, and that those organisms which happen to have the combination of factors best suited to the environment will survive and reproduce, while others will not.

Consequently (Darwin said), that combination of characters will be established as normal, and then the struggle begins again, until another combination, even more successful, arises.

Darwin believed that this was enough to account for the changes in species. Mendel's work showed up grave weaknesses in Darwin's arguments (not in his facts): and it is almost certain that, had Darwin been aware of Mendel's work, he would have modified his own arguments. He was a brilliant observer, and an honest man, but his work was widely misinterpreted by others who used it in attempts to prove that Man descended from the apes, and to deny the need for a Creator. These were not Darwin's aims: he offered the best explanation he could for an enormous accumulation of facts. The facts have proved extremely valuable: but the explanation was not good enough.

Evolution of Man.

Did Man evolve from lower animals? This question has been in men's minds for almost a century and is still unsolved.

At present there is room for honest doubt on the point, and one would scarcely be eager to include lemurs, reptiles and invertebrates in the family tree unless there was no chance of disputing their right to a place there. In any case, it should be clearly understood that the possibility of evolution of Man applies only to his body. The soul of each human being is created separately at the moment of conception The Bible account does not eliminate the possibility of the evolution of Man's body, but states specifically that the formation of the soul is an act of special creation, distinct from the formation of the body.

QUESTIONS

1. Describe the aims and methods of scientific investigation, and show how you would apply them to one of the following problems: (*a*) is a day-old puppy blind? (*b*) does the existence of dandelion-clocks mean that every flower in each head was visited by an insect?
2. Show with the help of diagrams, the difference between ordinary cell-division (mitosis) and reduction-division (meiosis).
3. Write short notes on the following: recessive, hybrid, Mendel's ratio.
4. State the main types of evidence for evolution. What other problem arises, if evolution is accepted?

CHAPTER XXIII

INSECTS

By far the majority of the animals in the world belong to the group of invertebrates known as arthropods (Greek: jointed limbs). This group includes the crustaceans (crabs, lobsters, shrimps, prawns, etc.), the millipedes and centipedes, spiders and scorpions and, most important of all invertebrates in many ways, the *Insects*, which form the most numerous single group in the whole animal kingdom. The insects owe their success to two main factors—the incredible diversity of their diets, and the possession of wings. There is scarcely any kind of organic substance which will not provide food for insects of some kind, or their larvæ. This may have inconvenient results for mankind, as in the case of the clothes-moth, wood-boring insects, etc.

Many of the features of insects are shared with all the arthropods, as, for instance, the many-jointed limbs, and the fact that the skeleton (page 114) is external (see below). Insects have some characteristics which are not found in other arthropods: and of these the most important is the fact that the body is sharply divided into three distinct parts (Latin: *insectum*, cut-up), called the *head*, *thorax* and *abdomen*. The three parts have slender connections between them (hence the term "wasp-waist"). Another easy means of distinguishing insects from other animals is that, during part at least of its lifetime, every insect has six legs. Thus, there should be no danger of your mistaking a spider for an insect: because its body is in two parts, and it has eight legs. The majority of adult insects have one or two pairs of wings.

This chapter deals with some well-known insects, and their structure will be illustrated by considering the structure of the cockroach which is bigger than most and fairly easily obtained (Plate VIII).

Structure of an Insect.

The body is clothed in a thick tough cuticle made of a protein called chitin (page 112), and this constitutes the skeleton, which is therefore external.

The *head* bears a pair of large *compound eyes*. Each of these has several hundred lenses, each producing a slightly different image, since it points in a different direction from all the others. It is difficult to imagine what effect this must have on the sense of sight; but it has the obvious advantage that the insect can see all round its body at once. There is thus no need for the eyes to be movable. This is one reason why flies are difficult to catch with one's hand.

> INQUIRY 128. Try catching resting flies with a cupped hand. The only successful way to do this is to sweep them up quickly from behind. This is not because they cannot see behind, but because the structure of the limbs compels them to "take off" by leaping backwards.

Projecting from the front of the head are two long slender jointed feelers called *antennæ*. The mouth has two pairs of horny jaws, and two pairs of short feelers which appear to serve as taste-and-touch organs. They are called palps (Latin: *palpo*, I touch).

The *thorax* is in three segments, and the cuticle between them is thin, enabling them to move slightly on each other. Each segment carries a pair of many-jointed *legs*, ending in hooked claws. The middle segment of the thorax has a pair of horny wing-covers growing from it. They are really modified wings. The hind segment bears a pair of *filmy wings* which, when not in use, fold up under the covers. The female cockroach has no wings or covers.

The *abdomen* has ten segments, but the last three are telescoped together. Each segment is bounded by a dorsal and a ventral plate, connected at the sides by softer cuticle. This structural arrangement is important in breathing. The last segment is notched, and has a pair of jointed rods projecting under it.

Respiration in insects is carried out by the pumping of air through a system of tubes (*tracheæ*, from Greek *tracheia*, windpipe) running throughout the body. Air enters the tracheæ through a series of holes called *spiracles* (Latin: air-holes) in the insect's sides. The cockroach has ten pairs of these: two pairs on the thorax, and eight pairs on the abdomen.

Air is pumped through the tube by the raising and lowering of the dorsal plates of the abdomen. These are slightly arched, and are pulled flat by muscles stretched between them and the ventral plates (Fig. 123). This forces air out of the body: and when the muscles relax the elasticity of the dorsal plates restores them to their arched shape and air enters to fill the space.

The *alimentary canal* is almost straight. The fore-gut is divided into a short *œsophagus*, a large thin-walled, sac-like *crop* (flanked by two pairs of salivary glands) and a muscular *gizzard* containing six horny teeth. The gizzard and part of the crop are in the abdomen. The gizzard is connected by a short tube (the mid-gut) to the slightly-coiled hind-gut. This has three regions: the *ileum*, *colon* and *rectum*. Attached to the ileum are a bunch of fine excretory tubes called Malpighian tubules. The colon is wider than the ileum, and leads into the very short rectum, which ends at the external opening, the *anus*, at the end of the abdomen. The whole alimentary canal is surrounded by a mass of fat.

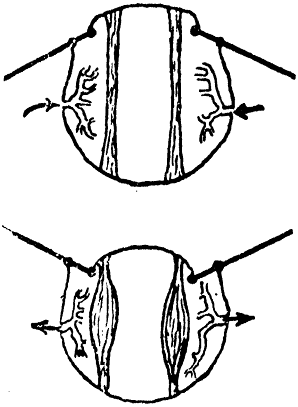

FIG. 123.—Showing how an insect breathes.

Reproductive system. The male has a pair of testes buried in the fat-body, beneath the dorsal plates in the middle of the abdomen. From these, a pair of vasa deferentia (page 270) lead to the sperm-sacs, and from there a short muscular tube leads to the exterior, just below the anus.

The female has sixteen ovaries, in two bunches, in the hind portion of the abdomen. The eggs pass through the two oviducts which have a single opening to the exterior near the anus.

On their way out the sixteen eggs are fertilized by sperm, received from a male cockroach and stored in a spermotheca in the abdomen. The sixteen eggs are then enclosed in a single capsule and laid.

Life-History of Cockroach.

The development of most insects involves one or more metamorphoses (page 153), but the cockroach which emerges from the egg is very like an adult in appearance, though extremely small. These insects like warm, dark, dry places, and so are often found in bakehouses, kitchens, and the holds of ships.

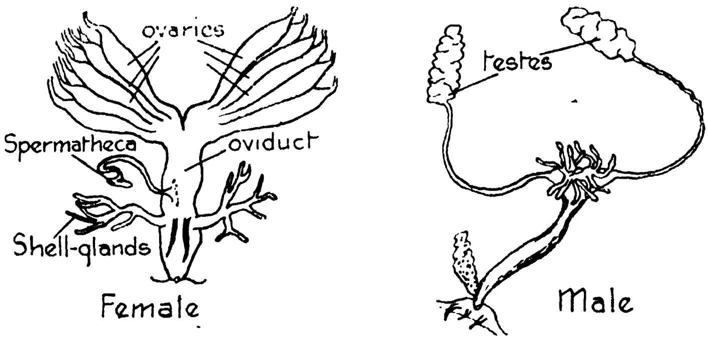

FIG. 124.—Reproductive organs of Cockroach.

They feed on grain, food-scraps, and other insects (including cockroaches). Since their skeleton is external (exoskeleton, contrast with endoskeleton of vertebrates), they cannot grow steadily in size, but they grow in a series of *moults*. The internal organs grow until they burst the cuticle, which splits along definite lines and is cast off and often eaten. Then the insect expands as much as possible while its new cuticle is hardening. The whole process may be repeated several times before adult size is reached.

Fertilization, as in all insects, is internal; but the cockroach does not lay nearly so many eggs as most other insects.

Cockroaches belong to the orthoptera (Greek: straight-winged) group of insects, which includes crickets and grasshoppers. There are 18,000 known species of orthoptera.

Butterflies.

Butterflies and moths belong to the lepidoptera (Greek: scaly-winged). Each has two pairs of wings, on the middle and hind segments of the thorax. They may be distinguished from each other by the fact that moths have pointed antennæ, while the antennæ of butterflies have club-shaped ends. There are 120,000 species in the lepidoptera, and we shall confine our attention to the *Cabbage White Butterfly.*

This insect lays clusters of cream-coloured fluted eggs on the undersides of the leaves of cabbages and other garden plants. A green *caterpillar* (Latin: hairy cat) emerges from the egg. The caterpillar is the *larva* (page 154) of the insect. It is long and slender, with a segmented body. The head has biting jaws, and the first three segments behind it carry three pairs of *true legs.* Four segments of the abdomen have projections which are called *prolegs.* On the front of the head is a silk-producing gland called a *spinneret.*

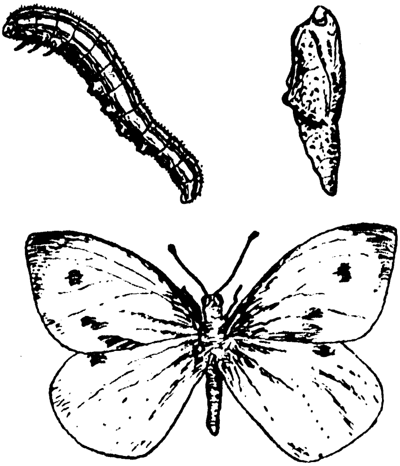

FIG. 125.—Larva, pupa and adult Cabbage White Butterfly.

The larva eats its egg-case, and then turns its attention to the leaves of plants. It feeds greedily for some time and then, if it has escaped the attention of gardeners, birds and ichneumon flies (which lay their eggs in caterpillars' bodies so that their larvæ can feed on the caterpillar), it finds a sheltered spot and spins a silken pad with silk which it squirts through its spinneret. Attaching the pad to a firm support, it grips it with its last pair of prolegs and spins round itself a silken sling which supports the whole weight of the larva, hanging head-downwards.

After a couple of days the larval skin splits, rolls up and falls off, leaving the *chrysalis* (Greek: cold-coloured) or *pupa* (Latin: baby) exposed. This has at first a transparent skin, through which all the features of the future butterfly can be [illegible] but the skin is quickly covered with a fluid which hardens and darkens in colour. In this condition the pupa rests while internal changes occur. If this stage is reached in early summer, it lasts for about three weeks; but if it is reached in late autumn, it lasts throughout the winter. At the end of the resting-period the pupa-case splits down the middle, and a perfect adult butterfly the *imago*, emerges.

The adult butterfly has two pairs of large wings, covered with many thousands of tiny scales. When at rest the wings stand erect, their upper surfaces closed together. In moths, the wings are usually horizontal when at rest; but there are too many exceptions on both sides for this to be a reliable way of distinguishing them. The mouth-parts are specially shaped to enable the insect to reach down into the tubes of flowers. The *proboscis* (Greek: trunk), formed from one pair of jaws, is a long tube, coiled up under the head when at rest, but capable of straightening out and probing in flowers for nectar, on which the adult insect feeds.

The brilliant colours seen on the wings of many butterflies are caused, not by the presence of pigment, but by very fine ridges on the *colourless* wing-scales. These ridges act like prisms and split up the white light falling on them.

> INQUIRY 129. Collect leaves of cabbage or nasturtium plants bearing eggs of the cabbage white butterfly. Keep them in a large glass vessel with a sprinkling of water, and watch the metamorphosis described above.

Houseflies.

Houseflies belong to the diptera (Greek: two-winged). There are 75,000 species in this order, including mosquitoes, crane-flies, midges and gnats.

The wings are transparent and attached to the middle section of the thorax. The third segment of the thorax carries, instead of wings, a pair of small club-like "balancers".

A female fly lays tiny white eggs, singly, on manure, or meat, or decaying food. One fly may lay one hundred eggs daily over a long period. The larva is called a *maggot*. It is legless, and unlike the caterpillar, has a pair of compound eyes. In less than a week's feeding the maggot reaches full size (about half an inch long). It pupates inside its larval skin, which forms a pupa-case. Inside the case metamorphosis takes place fairly quickly in warm conditions, and in less than a week the adult fly breaks out of the case. In cold conditions the pupa may pass the winter in its resting-stage. Adults sometimes hibernate.

The adult has a hairy body, and the hairs, especially on its feet, pick up disease germs from the filth on which the insect feeds. Its feeding-mechanism is an efficient suction-pump. It feeds by disgorging on to its food some of the saliva and other digestive juices from its glands. The juices liquefy the food, which is then sucked up through a pad at the end of its tongue by a pumping action of its stomach (Plate V).

The legs have adhesive pads at their tips, which enable the fly to walk upside down, and on smooth surfaces such as glass. Flies, in common with all other insects, do not grow after metamorphosis has been completed. Different-sized flies either belong to different species, or have had different opportunities for feeding in the maggot-stage. The fly's wings beat about three hundred and fifty times a second.

The life-history is more easily observed in the blow-fly (Blue-bottle), which is very similar, but bigger.

> INQUIRY 130. Blow-fly maggots are obtained by leaving a small piece of raw meat exposed on a hot day. A female fly will find it and lay eggs on it. The maggots are the bait used for fishing and called "gentles". Observe the metamorphosis.

Honey-Bees.

Because of their highly-developed social habits, bees are among the most interesting of all invertebrates. In any colony of bees there are three types of individual. There is one *queen*, the only female which lays eggs. There are up to fifty thousand other females, but these do not lay eggs. They are called *workers*, and will be described in some detail. There are also several hundred male bees, called *drones*. These do not work, and when winter comes they are driven out of the hive to die. Fig. 126 shows the sizes of the three types.

The workers are specially modified to enable them to carry out their tasks, which include making the honeycomb, nursing the larvæ, and collecting pollen and nectar to feed all the bees in the hive. They convert some of this into wax and some into honey, in their bodies. The wax is secreted by glands on the underside of the abdomen, and passed forwards to the jaws, which are used to mould and build it into the comb.

The "tongue" with which the bee collects nectar is really a development of the lower lip. Pollen is collected mainly by the hairs on the body and legs. The hind-legs have each a hollow on the outer side, called the *pollen-basket*, and a tuft of stiff hairs with which the bee "combs" the pollen from its body into the pollen-basket. When the bee reaches the hive with its load (big enough to be easily visible when the animal is in flight) it removes the pollen from the baskets with the help of spikes on its middle legs.

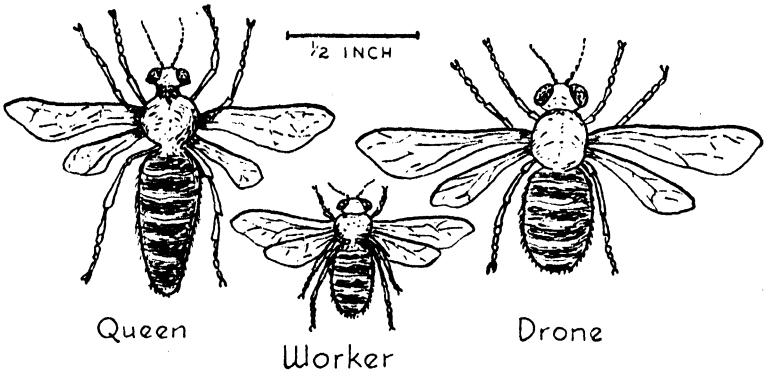

FIG. 126.—Bees.

The cells of the comb are geometrically shaped to make the most of the available material. Honeycomb cells are filled with honey and sealed with wax caps. Broodcomb cells are left open, and the queen deposits an egg in each, using for the purpose a pointed tube which protrudes from the tip of the abdomen. This is called the *ovipositor* (Latin: egg-placer), but it can also be used as a weapon, in which case poison passes down it from a poison-gland in the abdomen. In the workers the ovipositor is used only as a sting. It has barbs at the end which may prevent it from being withdrawn from its victim. The bee tears itself away, often with fatal results to itself.

Cells which are to accommodate drones are bigger than those for workers, and those for queens are bigger still. The queen deposits fertilized eggs in the queen-cells and worker-cells, and unfertilized ones in the drone-cells. It follows then, that female bees develop from fertilized eggs, and male bees from unfertilized ones. Whether a female is to become a worker or a queen is determined by the food it receives as a larva. All the larvæ in the queen-cells receive special food (see below).

The first food of all larvæ is provided by the workers from their own stomachs (regurgitated food): and future queens are fed in this way for about five days. The substance is therefore called "royal jelly". Future drones are very soon placed on a diet of pollen; while future workers are fed on honey. After five days all the larvæ are sealed in their cells, along with a supply of honey and pollen. Inside the cell, the larva finishes off its food and then pupates. This may take anything from a week for queens, to three weeks for drones.

When a new queen emerges this is the signal for a revolution in the hive. It may be bloodless, in which case a large number of workers leave the hive with the new queen, to found a new colony; or there may be a fight to the death between the rival queens. Several days after emerging the new queen performs a *nuptial* (Latin: marriage) flight, followed by a mass of drones, one of which overtakes the queen and provides her with a store of sperm which will suffice for her entire career. The drone then dies.

The honey and wax made by bees are valuable to mankind, and beekeeping is a very ancient industry.

> INQUIRY 131. Try to visit an apiary (Latin: *apiarius*; beekeeper), and observe the facts given above. Watch bees visiting flowers, and see how they deal with the pollen.

Other Social Insects.

Wasps live in much the same fashion as honey-bees; but their nests are often made of paper, fashioned from wood chewed by the workers.

Ants have a social life even more complicated than that of the bees. Leaf-cutting ants carry bits of leaf into their underground homes where other ants roll them into balls and cultivate on them a species of fungus, which provides a food-store for the colony. There is a species of ant which keeps a species of greenfly in its home, and by stroking it with its feelers induces it to give off a sweet substance which the ants use as food. Some species of ants raid the nests of other ants, robbing them of their pupæ, which they carry off to their own nests and rear as slaves. The "ant-eggs" which are sold as food for pet fish are really the pupæ of ants. Bees, wasps and ants belong to the Hymenoptera (membrane-winged) order, 86,000 species.

Economic Importance of Insects.

Insects may be either useful or harmful. Their importance in pollination has been mentioned already: and whether this is useful or the reverse depends on the plant under consideration. Many insects act as scavengers, destroying and burying dead animals and plants. Gall-flies modify plant-tissues into substances which can be used for industries such as tanning, dyeing and ink manufacture. Silk-worms (silk-moth larvæ) provide silk.

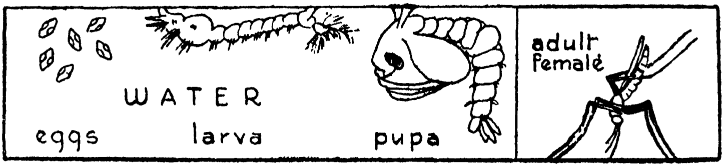

FIG. 127.—Mosquito.

Many animals used as human food feed themselves on insects. Insects therefore occupy a place in human food-chains (page 3).

The numbers of many harmful animals are reduced by insect-parasites.

Insects have entered into the art of many countries: in ancient Egypt certain types of beetle were considered sacred. (It should be noted that we have not dealt in this chapter with the biggest order of insects, the coleoptera [beetles] which include over a quarter of a million species.)

Injurious insects are mainly of three types: those which attack Man and useful animals, illustrated by parasites and the hosts and carriers of diseases (page 214); those which damage crops (crane-flies, green-fly, etc., page 215); and those which damage or destroy useful commodities such as clothes and furniture. Examples are the clothes-moth larva, termites, death-watch beetles, etc. There is even a beetle which eats through the lead covering of electric cables and causes short-circuits.

QUESTIONS

SECTION A.

1. Make a list of the features which are common to all insects, and illustrate their presence in one named example.
2. Account for the fact that few insects reach a large size.
3. Describe the cockroach as a typical insect, pointing out which features show important modifications in other types of insect.
4. Describe the life-history of a butterfly, and give diagrams of the larval stages.
5. Describe the life-history of the house-fly (or the blow-fly), and explain why these insects should be destroyed at every opportunity.
6. Describe the characteristic features of the three types of honey-bee.
7. Describe the organization of a natural beehive.
8. Write notes on three named beneficial, and three named harmful insects.

SECTION B.

1. Write a comparative account of the external structure of the cockroach and the butterfly.
2. What is the value of the pupa stage in the metamorphosis of an insect?
3. Write a short account of the feeding-methods of insects, and the modifications of mouth-parts involved in different methods.
4. Write an essay on the economic importance of insects.

CHAPTER XXIV

FISH, REPTILES AND BIRDS

Our study of vertebrates has so far covered only the amphibia, represented by the frog, and the mammals, represented by Man and the rabbit. The other groups, although less conveniently studied in school, cannot be neglected.

Fish.

The fish are placed lowest in the vertebrate scale for reasons which can be discovered by a simple study of their structure and habits.

Skeleton. Many types of fish, including the skates, rays and sharks, have skeletons consisting entirely of cartilage. All types of fish are clothed in *scales* which, although not strictly part of the skeleton, assist the internal skeleton in maintaining the shape of the body and protecting it from injury.

Feeding. The alimentary system of fishes is broadly similar to that of other vertebrates, but more primitive. The teeth are simple, often only modified scales, and are usually all of the same shape. One of the biggest of all fish, the basking shark, is incapable of swallowing anything bigger than about the size of a walnut. It feeds on small fish which it strains from the water passing through its mouth.

Respiration. Fish, with very few exceptions, can only breathe dissolved oxygen. No fish has true lungs, though one type of fish, called the *lung-fish*, has an air-bladder which serves as a temporary air-breathing organ.

The normal respiratory organs of a fish are its *gills*: fleshy outgrowths on the walls of the pharynx, very richly supplied with blood-vessels beneath a very thin skin. Water enters the mouth continually, flowing over the gills and out through *gill-slits* on either side of the pharynx. In some fish the gill-slits are visible (sharks, rays, etc.), but usually they are covered by a flap, open at the back, called the *gill-cover*. As the blood in the gills is so near to the flowing water, gas-exchange takes place quite readily.

The heart has only one auricle and one ventricle, and develops from a simple S-bend in the main blood-vessel.

Reproduction. Eggs are laid by the female and fertilized externally by sperm which is shed into the water near them by the male. This rather haphazard procedure makes it necessary for enormous numbers of eggs to be laid. A single fish may lay several million eggs in one season. Development is very precarious. There is no larval stage, and the young fish which hatch out of the eggs are seized as food by other fish. This so reduces their numbers that, of all the millions of young fish which theoretically could be produced from the eggs, only an average of two fish survive to reach maturity, thus keeping the fish-population fairly constant.

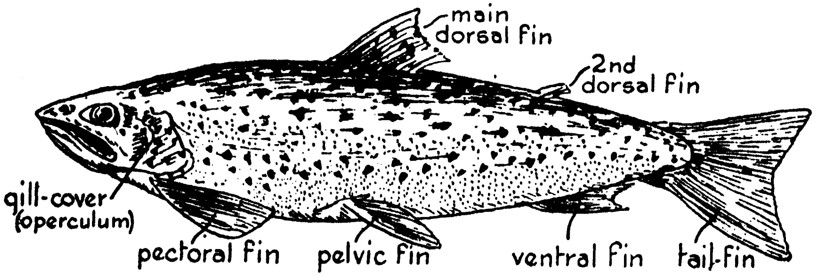

FIG. 128.—Salmon.

Fish-hatcheries. Artificial protection is provided for many types of fish, especially plaice, in fish-hatcheries, where the fish are allowed to develop safely in indoor tanks: and the fish, when big enough to swim away from danger, are dumped back into the sea, to provide bigger catches for the trawlers in the future.

Sense-organs. The sense-organs of fish (except olfactory senses) are generally less well-developed than those of other vertebrates. The lens of the eye is spherical, and it focuses by moving backwards and forwards. The ear corresponds only to the inner ear of a mammal, and is almost exclusively concerned with balance rather than with sound.

Locomotion. The fish moves with the aid of thin structures called fins projecting from its body. The shape of the body lends itself to smooth gliding movement through the water. The fins are of two kinds—paired and unpaired. There are two pairs of paired fins, and they are the animal's limbs. The pentadactyl plan cannot be observed even in the skeleton of the fins. The front limbs (*pectoral fins*) are attached to the pectoral girdle, and are usually bigger and more powerful than the *pelvic fins*. The fins act mainly as elevators, propulsion being caused by movements of the tail, which also acts as a rudder.

The unpaired fins are on the middle-line of the body. There may be one or more dorsal fins, one or two ventral fins, and a caudal fin which fringes the tail.

> INQUIRY 132. Observe small fish in an aquarium. Notice the movements of the limbs, and the continual opening and closing of the mouth. See how the gill-covers move in harmony with the mouth movements.

Queer Fish.

There is great variety in the life-histories of different kinds of fish. One of the most remarkable is that of the *eel*. All the eels in the rivers of Europe have swum, or been carried by currents, in their early days, from the Caribbean Sea across the Atlantic Ocean. They reach the western shores of Europe as small transparent "glass-eels" about the size of an earthworm. They make their way up-river and, after several years, during which they grow to about a yard in length and four inches in diameter, they begin the long journey back to their spawning-grounds in the Caribbean. There they die, and the tradition is carried on by the next generation. This is an example of migration, a feature in the life-history of many animals, but commonest among the birds (page 303).

Reptiles.

Little space can be afforded for a description of these interesting animals. They include such varied creatures as snakes, lizards, chameleons, crocodiles, turtles and tortoises. They are covered with scales and seldom have limbs strong enough to support the weight of the body. They are cold-blooded, and most of them hibernate.

Snakes are remarkable for their ability to propel themselves rapidly without external limbs. They really move on the points of their ribs. The wriggling motion is always horizontal—that is, the body curves without arching from the ground. Artists often forget this.

Another peculiarity of many snakes is the elastic connection between their jaws, enabling them to swallow animals several times wider than themselves. A common grass-snake, less than one inch in diameter, will readily swallow a duck-egg, two inches in diameter. The neck swells out, clearly showing the shape of the egg, which is then crushed by powerful muscles.

Poisonous snakes have hinges on their fangs and a poison-sac at the root. When the snake strikes the fangs are erected and poison is forced down a central canal in the tooth.

Birds.

Except for mammals, birds are the most highly developed animals. They have warm blood (page 175) and have a four-chambered heart very similar to that of mammals. Their sense of sight is much more efficient than that of mammals, and their wing-muscles are often much more powerful and quick-acting than any muscles in mammals. The wings of a humming-bird have been shown to beat two hundred times a second. A blow from the wing of a swan is enough to break both legs of a man. A swallow can fly at over a hundred miles an hour.

Brain-power in birds is far less than in mammals; but parental care is often very highly developed, and they possess uncanny instincts which assist them in migration.

Migration.

Many birds spend part of each year in one part of the world, and the rest in another place, perhaps over a thousand miles away. Yet after the double journey they succeed in finding the exact spot which they left the previous year. The exploits of homing pigeons are well known, and were of great value during the war, when they were used as an official branch of the Forces for carrying messages.

No one has yet discovered either the cause of migration, or the means by which it is directed. It is true that a bird has a much greater range of vision than a mammal, and may be able to perceive infra-red rays which would enable it to "see in the dark". It has also been found that powerful radio transmitters in action seem to interfere with the homing instincts of pigeons. These two facts suggest that visual memory (recognizing landmarks) and electrical conditions in the atmosphere may be factors in migration. The first of these cannot apply to many young birds which, starting several weeks after their parents, on a journey completely new to the offspring, find their way unerringly to the same place as their parents.

Most migrant birds in the northern hemisphere fly southwards on the approach of winter. Thus, in this country, we have winter visitors and birds of passage from the north and summer visitors from the south. It seems that warmth and plentiful food must be important factors in migration; but there are cases which make even this theory rather doubtful.

Migration is not confined to birds. An example of its occurrence among fish has already been given (page 302), and it is well known that herring fleets in the North Sea have to follow the migration of shoals which keep scrupulously to a regular schedule. Migration is also found among mammals. One of the most curious examples is that of the *lemmings*. These are rat-like mammals which live in Scandinavia. At intervals of several years the entire adult lemming population suddenly sets out on a journey westwards, which eventually brings them to the North Sea. This does not stop them; they plunge into the sea and swim on westwards until they drown or die of exhaustion. The young lemmings left behind in Scandinavia build up the race again.

Special Features of Birds.

Locomotion. The fore-limbs of most birds are modified to enable them to fly. There is usually a strong breast-bone or *keel*, to which are attached powerful muscles which make up much of the bird's weight. These work the wings, which, built on a pentadactyl skeleton, are covered with feathers, and so shaped that, when extended and beating downwards, they compress the air beneath and behind them. This lifts the bird forwards and upwards. The tail acts as a rudder and a brake. There are many differences in the details of wings and their rate of beating.

The whole body is designed to assist in flight. It is streamlined so that the air flows smoothly past as it flies; the bones are hollow, and this reduces the density of the body. The temperature of the blood is higher than in mammals, and this presumably means a higher rate of energy-release, corresponding with the powerful muscle-action. Feathers are light in weight and, both by themselves and by trapping air in their spaces, help to retain heat in the body. The eyes have thin transparent third lids which can be drawn over them for protection when the bird is in rapid flight.

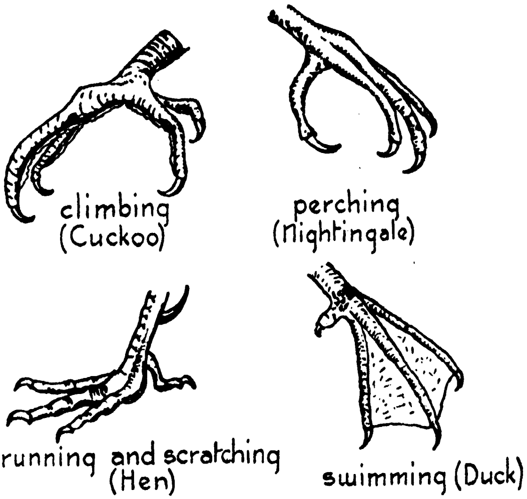

FIG. 129.—Feet of common birds.

The lower limbs of birds are greatly modified in accordance with the type of environment. There are only four toes at the most and they are specially shaped for gripping twigs, or for wading or swimming (Fig. 129). Birds which live in trees can lock their toes so that they will not fall from the twig while asleep. Swimming birds have skin webs between the toes, giving them a bigger purchase on the water. Penguins, which spend most of their time in the sea, cannot fly, and their wings are modified into fin-like flippers.

Feeding. The mouths of birds are very specialized according to the type of food they eat (Fig. 130). Birds do not have teeth, but instead have a horny beak which can crush the food into small pieces. In the upper part of the alimentary canal of those birds which eat seeds there is an apparatus for grinding the food (the gizzard), which often contains small stones to help in the grinding process. This explains why fowls must be provided with grit along with their food. A remarkable state of affairs is found among some sea-birds which live for part of the year on grain and for the rest on fish. Their alimentary canal undergoes a reorganization twice a year, from a typically herbivorous to a typically carnivorous digestive system (page 57) and back again.

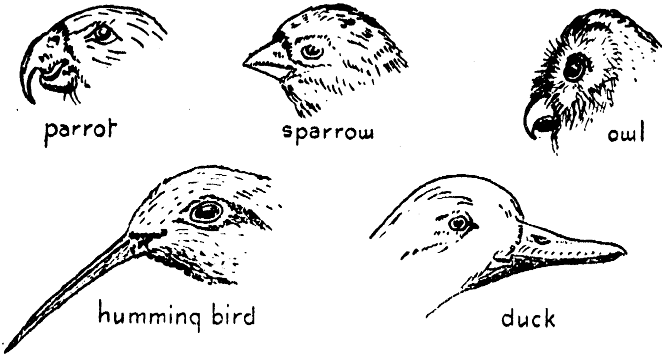

Fig. 130.—Beaks of birds.

Bird-song is closely connected with mating and the care of the young.

Development. Birds lay hard-shelled eggs. The shell, made of chalk, is porous, allowing gases to pass through it. The contents, enclosed in a thin membrane, consist of a store of thin food-solution, mainly protein, and a slightly thicker coloured yolk which contains a high proportion of fat. Resting on the upper surface of the yolk is the living part of the egg, a flat *germinal disc* (about one-eighth of an inch diameter in a hen's egg). It is from this that the chicken develops, absorbing the food inside the shell and breathing through its pores. The disc is kept right-way-up (nearest to the warmth of the parent's body during hatching) by two strings of mucus which twist as the egg is turned. The parent turns the egg at regular intervals to prevent the disc from sticking to the shell. Sometimes development is artificially speeded up by heating the eggs in an incubator.

The young bird pecks its way out of the egg (after twenty-one days in the case of a hen's egg), and may be at once able to run about and peck its food. This is seen with hen-chickens; but the young of most wild birds are helpless for a short time after hatching, and are fed by their parents who drop insects, worms or grain into the mouths of the offspring. The noisiest chick is fed first. It then becomes quieter than the others, so the parents do not make the mistake of leaving out one chick and feeding another twice.

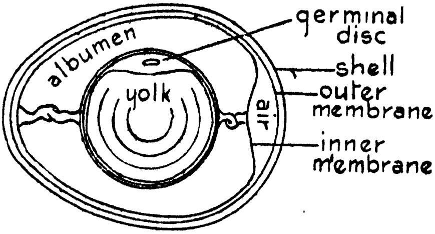

FIG. 131.—Section of hen's egg.

The parental instinct is often very highly developed in birds and is expressed not only by their care in hatching the eggs and feeding the young but by elaborate nest-building in carefully-selected places, and by their fierce defence of their young against marauders, and their "patience" in teaching their offspring to fly and to find food.

Distinctive Features of Vertebrate Groups.

The following summary shows mainly how the five groups of vertebrates may be distinguished from each other. Points of similarity are sometimes included for completeness, but most of these should be found from the text.

Fish, amphibia and reptiles are cold-blooded; birds and mammals warm-blooded.

Breathing. Fish breathe dissolved oxygen through gills. Amphibia breathe dissolved and free oxygen, and at different stages may use any or all of these methods: gills; absorption through skin; lungs. Reptiles, birds and mammals have true lungs, helped in some cases to a slight extent by skin-breathing.

Heart. Fish have a two-chambered heart (one auricle, one ventricle).

Amphibia have a three-chambered heart. Reptiles have a three-chambered heart with partial separation of the ventricle into two. Birds and mammals have a four-chambered heart.

Skeleton. The proportion of permanent cartilage becomes less as we ascend in the order—fish, amphibia, reptiles, birds, mammals.

Covering. Fish have scales covering the whole body. Amphibia have a naked skin. Reptiles have scales covering the whole body. Birds have scales on the legs, but the body is covered with feathers. Mammals have no scales and the body is covered, at least partly, during some time in the life-cycle, with true hair.

Limbs. The pentadactyl limb is found, under many guises, in all groups except fish. Some reptiles are limbless, and some birds have functionless (vestigial) wings.

Reproduction. Egg-laying forms are found in all five groups, but are exceptional in mammals whose young are usually born fully-formed and suckled by the mother. In exceptional cases among fish, amphibia and reptiles, the eggs may hatch inside the mother's body, as they do in mammals. Such animals are *viviparous* (Latin: bringing forth alive).

QUESTIONS

Section A.

1. What characteristics of fish distinguish them from other vertebrates? What features do they share with other vertebrates?
2. Give a labelled diagram of a fish, showing its chief external features.
3. Compare in outline, the life-history of a fish with that of a frog.
4. Make a list of the characteristics of a bird, and in the case of either the beak or the wings give three examples of different types, with uses.
5. In what ways is a bird specially adapted for flight?

6. Describe the structure of a bird's egg.
7. Compare the limbs of a bird with those of a bat, and describe how the difference in structure of the animals is reflected in their manner of flight.
8. State, giving reasons, in which group you would place each of the following: mouse, slow-worm, whale, newt, lizard, penguin.

SECTION B.

1. At one time reptiles dominated the earth. How did they lose that domination?
2. Explain how water-glass (sodium silicate) preserves hen-eggs.
3. On what grounds are the birds placed below mammals in the vertebrate scale?
4. Write a short essay on "Vision in Vertebrates".

Chapter XXV

COMMUNITIES

The word "community" (Latin: fellowship, mutual participation) has two different, although related, meanings, according to the circumstances in which we use it. When we speak of "the community", we usually mean the general public, and are thinking of the many different kinds of people who, taken together, make up "the common man". When, on the other hand, we refer to a "community of nuns", we are thinking of their uniformity of calling rather than their individual differences. In biology, the word is generally used in its first meaning, to cover a group of living things which may show great variation among themselves, but taken together form a recognizable unit in which all the different forms play their parts.

Examples of communities are: woods and forests, jungles, meadows, prairies, moors and heaths, hedgerows and ditches, ponds and streams, deep-sea life, surface-life in the sea (plankton), etc. Their limits may be drawn by Man as, for example, when a hedge and ditch are made round a field, or when a clearing is made in a wood, or a new forest is planted; but their contents achieve a natural balance among themselves: and the nature and numbers of organisms will become fairly constant.

Thus, a meadow which has been made by clearing a section of a wood will become a natural meadow; but if left untended for years may be incorporated again in the wood. Everyone knows what happens when a garden which has been well kept is allowed to "run wild" for only three or four years. The carefully selected flowers, such as Russell lupins, or varieties of roses, become cross-pollinated and revert to hardier, though perhaps less attractive, forms. Air-borne seeds settle on the smooth lawns and weed-plants grow in profusion. Insect-pests, such as green-fly and cabbage-white butterflies, which were excluded as far as possible, return and thrive on the plants. Grass grows in the herbaceous borders, and flowers on the lawns. Hedges and bushes which had been carefully pruned to limit their size grow unrestricted and may reach a height of twenty feet or more. Moss may cover the paths, and if there is an ornamental lily-pond it may become covered with a film of green algæ. Voles, field-mice, and other small mammals will set up homes in the shelter of the vegetation, and birds will nest in the bushes.

Thus a thriving community arises with its own natural balance. It is not the kind of community we like to see in a garden: so, in order to preserve an artificial community such as a flower-garden and orchard, or a farm, constant attention is required. Such communities have no natural balance, and are always striving to achieve it. Successful cultivation depends on preserving the desirable features and excluding the others without straining the balance too far from the natural state.

Pond.

At the edges of a pond in a meadow the ground is sodden and is called *marsh*. It is populated with animals which spend their early stages in water, such as dragon-flies, gnats, mosquitoes and many other insects with aquatic larvæ; frogs which have just outgrown the tadpole stage, etc. A few mammals may be found, e.g. water-rats, shrews, etc. Note that all the animals are small, as the ground would not support heavy ones.

The plants include marsh-marigold, iris, watercress, rushes and sedges, and horsetails. The majority of these plants are noted for their vertical form, which enables large numbers of plants to occupy a small area. A few insectivorous plants may also be found, for reasons given on page 35.

Passing on into the pond, we reach the shallow water first, with its aquatic larvæ, small fish and newts, nests of water-birds and masses of algæ such as spirogyra. Tall bulrushes mark the inner edge of this stretch, and the open water of the pond contains water-lilies, floating duckweed, water-crowfoot, pond-weed and Canadian water-weed. The animals include water-beetles, pond-skaters, water-fleas, fresh-water shrimps, water-snails, flat-worms and fish.

The presence and activities of all these organisms results in a balance of the proportions of dissolved oxygen, mineral salts, acidity, food supply, shelter, and other factors; capable of supporting a certain population.

The rate of reproduction of the organisms in the locality will always lead to a surplus of individuals; and in these circumstances a struggle for survival is inevitable. This struggle, however, should not be thought of in the human sense of a conscious feud, accompanied by "bitter feelings." It is almost certain that all plants and most animals are incapable of feeling in this sense. The struggle is no less real, for all that, so that only a very small percentage of the individuals which begin life in the community, survive to reach the adult state and reproduce themselves. It was on these facts that Darwin based his theory of natural selection (page 287).

Aquarium.

The difficulty of observing life in ponds and streams has led to the establishment of "artificial" indoor aquatic environments for the purpose. Such a structure is called an aquarium (Latin: *aqua*, water). It consists of a glass tank with clean gravel and sand at the bottom. Shoots of aquatic green plants are wedged into the sand (e.g. Canadian water-weed, hornwort, vallesnaria, starwort): and after filling the tank with water (preferably pond-water or rain-water), the arrangement is left for as long as possible to become balanced and acquire the temperature of the room. During this time the sand sinks, the plants aerate the water and may grow adventitious roots, and the water acquires the correct proportion of acidity. Microscopic plants and animals will also establish themselves. Larger animals may then be introduced.

Care must be taken not to introduce into the same tank animals which will proceed to fight to the death (unless this is the subject of an inquiry). Thus, larvæ of the great brown water-beetle will promptly attack tadpoles, small fish, and each other. Water-snails will help to keep the glass clean by eating algæ which settle on it. Small fish will soon settle down; but if they are young specimens of fish which will grow to considerable size (e.g. perch) they should be removed before they become big enough to leap out of the tank. It is interesting to introduce caddis-fly larvæ and watch them building little tunnels round their bodies from fragments of gravel.

If amphibia are included they should be provided with means of climbing above the surface, otherwise they will drown (page 171).

If there are sufficient plants, and the tank is well-lighted, the water will remain fairly rich in oxygen; but it is usual to blow air through it at regular intervals to freshen it up. Refuse should be removed regularly to avoid the growth of fungi. The golden rule is, not to have too many animals. There is always a temptation to "put everything in the shop window": but this puts too great a strain on the environment and the water becomes foul.

Woods.

In any wood a particular kind of tree usually predominates; and so we commonly hear of pine-woods, oak-woods, beech-woods, birch-woods, ash-woods. The factors which determine which kind of tree will succeed in a given place are very numerous. Examples are: soil-composition and climate (including the effect of altitude, slope of ground, etc.).

Beech-woods and ash-woods are common on chalky soils; oak-woods and birch-woods are more at home on non-chalky soils. Mixed woods (especially oak and ash) are found on intermediate soils. Each type of wood has associated with it characteristic groupings of smaller plants and animals.

Beech-wood. This is a useful example because it is easy to observe the relation between environment and organisms. Beech-trees cast a deep shade and, as a result, conditions inside the wood are unsuitable, after early spring, for green flowering plants. Almost the only flowering plants found in a beech-wood, therefore, are the very early-flowering dog's mercury, and the saprophytic bird's nest orchid. Many types of fungus abound in the deep shade. In the occasional clearings may be seen dog-violets. Around the edges of a beech-wood there are usually several types of shrub; the commonest is hawthorn.

Squirrels and insects are very numerous in beech-woods.

Ash-wood. The narrow leaves of the ash, appearing in late spring, cast little shade, and there is consequently plenty of light under the trees. As a result, many different kinds of shrubs are able to thrive, forming a dense undergrowth. Sometimes they grow so thickly that herbaceous plants cannot thrive beneath them; but usually there is a thick carpet of green vegetation of all kinds, providing food and protection for a great variety of animals.

Oak-woods are of two kinds. The commoner kind is populated by a species of oak whose flowers are on short stalks (pedunculate); while the less common kind, found in dry situations, contains oaks whose flowers have no stalks (sessile).

In a pedunculate oak-wood (damp oak-wood), found on heavy clay or loam, there is often a sprinkling of other trees, such as birch, maple and ash, and a thriving population of shrubs, including hazel, hawthorn, holly, blackberry, rose, willow and honeysuckle. Among the herbs of the undergrowth will be found primroses, anemones, wood-sorrel, wild strawberry and lesser celandine. In some areas, other types of flowers may be closely associated with oak-woods. Occasionally, the flowering plants may be crowded out by bracken.

In a sessile oak-wood (dry oak-wood), bracken is almost always found, and the only other plants prominent in the undergrowth are soft grass and bluebells; while the holly is the most characteristic bush.

Pine-woods. Here again the growth of herbs under the trees is greatly restricted, partly by the shade, but mainly by the deep carpet of pine-needles (fallen leaves), which take a long time to decay, and smother any tender green plants as well as sheltering them from the light. The plants of the undergrowth in these woods, therefore, are usually fungi, which obtain their food ready-made. As pine-woods usually grow on raised ground, any clearings are usually covered by heather, furze and broom-plants, which are characteristic plants of hillside and moorland.

In this short review of woods, little reference has been made to animals. The squirrel, fox and innumerable types of insects are found in all kinds of woods. The bird-population of woods is always very extensive, including about eighty to a hundred species, of which owls, kestrels, wood-pigeons and woodpeckers are well-known examples.

Hedges.

Although a hedge is in a sense an artificial, or man-made environment, hedges have become so well-established in this country that a natural balance has arisen. Trees include hazel, hawthorn, blackthorn, field maple. Climbing plants such as convolvulus, rose and blackberry mingle among the other hedge bushes and trees. The herbs include long grasses, ferns, violets, primroses, bluebells, wild arum, foxglove, dead-nettle, stitchwort, and dock.

Hedgerow animals include field-mice, hedgehogs, weasels, snails, glow-worms and the caterpillars of many butterflies and moths. Birds in the community include chaffinches, hedge-sparrows, robins, blackbirds and thrushes.

QUESTIONS

Section A.

1. What is a biological community? Explain what is meant by natural balance.
2. Describe the community to be found in the pond.
3. How would you proceed to set up an aquarium, and what organisms would you introduce into it?
4. Account for the difference in the undergrowth of a beech-wood from that of an ash-wood.
5. Describe the flora (plants) and fauna (animals) you would expect to find in a damp oak-wood.
6. What organisms, if any, would you find in a permanently dark cave?
7. Compile a food-chain for an owl.
8. Name the chief members of a seashore community.

SECTION B.

1. Suggest what would be the effect on the community living in it if all the trees of a beech-wood were felled.
2. How do patches of waste ground become colonized by organisms? Describe the succession of organisms one might expect on a patch of freshly uncovered soil in the middle of a town.
3. What would be the effect on a pond community if the whole surface of the pond were covered with a film of oil?
4. Describe the process of returning to a wild state which takes place on an untended lawn.

APPENDIX A

NATURE CALENDAR

THE following notes give some indication of the observations and activities which will prove profitable at various times in the year. The dates are based on sea-level in the south of England.

JANUARY. During the resting season, which is at its peak in this month, it is best to carry out practical work which is independent of the season, such as examination of skeletons, preserved specimens, etc.

Animals. The robin and the owl. Look under stones for hibernating creatures. Earthworms are always available, but burrow more deeply in frosty weather. Suppliers usually have all-the-year-round stocks of microscopic animals, and they travel better in winter.

Plants. Winter twigs. Examine dry fruits of last season. Germination of seeds may be started to give a chance of completing life-cycle during term.

FEBRUARY. In a mild year, hibernating insects become active, and spring flowers appear. Winter twigs will develop indoors. In a severe winter this month is best devoted to work on the physiology of plants, as the shoots will be available from indoor plants.

Animals. Rooks begin nesting. Observe chrysalis-stage of cabbage-white butterfly, for first signs of metamorphosis.

Plants. Spirogyra. Coltsfoot flowers (which appear before the leaves) are seen in waste places, and at this time not likely to be confused with dandelions, which are not yet out. Snowdrops, crocuses, lesser celandine. Opening of winter buds on trees.

MARCH. Frogs, toads and newts begin to spawn. Resident birds in full song.

Animals.	Frogs, toads and newts begin to spawn. Resident birds in full song (thrush, skylark, blackbird) without competition from summer visitors. Lambing season. Bats, hedgehogs, insects.
Plants.	Alder, hazel and willow catkins. Dandelions and daisies may appear. General reawakening of plant life.
APRIL.	
Animals.	Nesting in full swing. Migrant birds arriving—swallow, martins, cuckoo. Thrushes and blackbirds now laying. Young rabbits appearing. Cuckoo-spit (larva of an insect called a leaf-hopper) appears on stalks of grass. Leather-jackets (larvæ of crane-fly).
Plants.	Early fruit-blossoms—wild cherry, apple, etc. Larch-trees in leaf. Early purple orchid, lady's smock, marsh marigold, violet, wild arum, primrose.
MAY.	
Animals.	Most birds now laying. Tadpoles swarm in ponds. Insects laying eggs—look for eggs of cabbage-white butterfly on undersides of leaves in the garden. Larvæ of water-beetles, house-flies.
Plants.	Innumerable flowers. Horse-chestnut, hawthorn. Compare fully-developed leaves of as many trees as possible. Garden weeds.
JUNE.	
Animals.	Birds now have families of young. Tadpoles changing to frogs. Bees and wasps in evidence. Snails. Sticklebacks. Green-fly and other pests.
Plants.	Make collections of flowers and classify them.
JULY.	
Animals.	Bats, butterflies, glow-worms, dragonflies, grass-hoppers, ants.
Plants.	Summer flowers: rose, honeysuckle, poppy, rose-bay willow-herb, foxglove, water-lily.

AUGUST.	Harvest season beginning.
Animals.	If you visit the seaside look for sea anemones, lug-worms, crabs, sea-urchins, jellyfish and prawns. The latter are easily caught after dark with a torch, which attracts and dazzles them, and a long pole.
Plants.	Seaweed, marram-grass, sea-holly. Inland, soft fruits, wind-dispersed and animal-dispersed seeds.
SEPTEMBER.	
Animals.	Migrant birds leave the country in flocks. Gossamer spiders. Wasps.
Plants.	Leaf-fall beginning. Note autumn colours of leaves. Hawthorn, wild rose, bryony in fruit. Good month for fungi.
OCTOBER.	Hibernation begins.
Animals.	Insect pupæ available. Squirrels (which do not hibernate) busy collecting nuts for winter. Cooler weather suitable for dissection of rabbit, etc.
Plants.	The number of plants in bloom is small enough for a fairly complete record to be made.
NOVEMBER.	
Animals.	Birds which come here for the winter begin to arrive —wild swans, geese, redwing.
Plants.	Cultivated chrysanthemums, lichens.
DECEMBER.	
Animals.	Birds become tamer in severe weather. Furry animals have winter coats, e.g. stoat, otter.
Plants.	Observe winter outlines of trees. Study ever-green, including holly and mistletoe.

APPENDIX B

EXAMINATION QUESTIONS

N.U.J.M.B.: Northern Universities' S.C.
L.G.S.: London General Schools.
Cam.: Cambridge S.C.
C.W.B.: Central Welsh Board S.C.
Ox.: Oxford Local S.C.
O. & C.: Oxford and Cambridge Joint S.C.

CHAPTER I.

1. What are the characteristics which distinguish a living organism from a non-living substance? Which of the organisms known to you do you consider to be the simplest? Give reasons for your choice. (O. & C., 1946.)
2. What is (*a*) a cell, (*b*) a tissue? Describe briefly two types of cell from multicellular animals, and two from multicellular plants. (Cam., 1947.)

CHAPTER II.

3. How would you distinguish between the root and stem of a flowering dicotyledon? (C.W.B., 1947.)
4. Selecting either the stem or the root of a plant, describe (*a*) the internal structure as seen under a hand-lens (diagrams essential); (*b*) the work it does for the plant, and explain fully the way its structure enables it to carry out this work. (Cam., 1947.)

CHAPTER III.

5. Draw as accurately as you can from memory some named twig in its winter condition. Make notes on its method of branching and any other points of interest. (L.G.S., 1945.)
6. Describe three features of a horse-chestnut twig which enable it to survive the winter. Explain how to deduce the age of a twig from its external appearance. (N.U.J.M.B., 1947.)

CHAPTER IV.

7. Animals are great expenders of energy; plants are great storers of energy. Discuss this statement with reference to amœba, spirogyra, Man and a tree. (L.G.S., 1946.)

8. Transference of energy is involved in all processes of living things. What is the source of this energy, and how is it obtained, stored and released by (*a*) green plants, (*b*) animals? (Ox., 1945.)

CHAPTER V.

9. (*a*) Name four metallic elements which are essential for the life-processes of living organisms. (*b*) State one way in which green plants obtain their nitrogen, and one way in which green plants may supplement this supply. (*c*) What is meant by metabolism? (*d*) Name the vitamin which is essential for the growth of bone, and state one natural source from which it may be obtained. (N.U.J.M.B., 1946.)
10. State briefly the part played by water in the lives of animals and plants. (O. & C., 1947.)

CHAPTER VI.

11. (*a*) From what external source does a green plant obtain its energy? (*b*) Explain carefully how this energy is absorbed, stored and released in the plant. (*c*) Name the process by which the energy is released. (*d*) How would you show experimentally that some of this energy is released in the form of heat? (N.U.J.M.B., 1946.)
12. What is osmosis, and how does it resemble diffusion? Describe an experiment to demonstrate osmosis and give one instance of its use in (*a*) plants, (*b*) animals. (Ox., 1946.)
13. What is transpiration? Describe an experiment by which you could prove that the leaves of a plant transpire. How does sweating resemble and differ from transpiration? (Ox., 1947.)

CHAPTER VII.

14. How would you show that carbon dioxide is used in photosynthesis? Make a list of five important differences between respiration and photosynthesis. (N.U.J.M.B., 1947.)
15. Explain how you would show experimentally that (*a*) light, and (*b*) chlorophyll, are necessary for the manufacture of starch by a green leaf. (L.G.S., 1945.)
16. What is meant by vegetative propagation, and how is it achieved by any three plants you have studied? (O. & C., 1947.)
17. Make three labelled diagrams to show the structure of (*a*) a potato, or a rhizome of Solomon's seal, or a rhizome of iris, or a corm; (*b*) a carrot, beet or raddish; (*c*) a named bulb. Label clearly the parts which are stem, leaf and/or root in each drawing. State for what purposes these organs are modified. (Ox., 1947.)

CHAPTER VIII.

18. Name the different kinds of mammalian teeth and state their functions. (L.G.S., 1946.)

19. What do you understand by bilateral symmetry? Give an example by reference to a named mammal, and state clearly the advantages it confers on the mammal. (C.W.B., 1946.)

20. What are the functions of the skeleton of a mammal? Give a labelled diagram of the skeleton of one limb of a mammal and carefully describe how it works. (O. & C., 1946.)

CHAPTER IX.

21. Describe the general anatomy of the alimentary system of a mammal. Draw up a table to show the digestion processes which go on in each part of the system. (L.G.S., 1947.)

22. Give an account of the structure and function of the thorax of a named mammal. (C.W.B., 1947.)

23. What do you understand by the terms (*a*) hormone, (*b*) endocrine organ? Illustrate your answer by reference to three endocrine organs of the human body. (Cam., 1947.)

CHAPTER X.

24. Describe in detail the mechanism of breathing in a mammal. How is the oxygen which is obtained during breathing carried to the tissues of the body? (Details of circulation not required.) (N.U.J.M.B., 1947.)

25. Describe the structure and functioning of the heart in either a frog or a mammal. Describe the functions of the blood. (O. & C., 1946.)

CHAPTER XI.

26. What do you understand by the term growth? Describe experiments you would perform to show respectively (*a*) where growth in length takes place in a stem, (*b*) the rate at which the stem is growing in length. (L.G.S., 1945.)

27. What is metamorphosis? Illustrate the phenomenon by reference to the life-history of a frog. Give large fully-annotated diagrams of three distinct stages in this life-history. (Ox., 1947.)

CHAPTER XII.

28. Describe the structure of a named seed. Make labelled drawings to show its appearance (*a*) a few days after germination has

started, (*b*) when it has reached the stage of producing fully developed foliage leaves. State three external conditions which are essential for germination. (N.U.J.M.B., 1947.)

29. What is meant by "soil"? Give a brief account of the main types of soil and their characteristic features. (L.G.S., 1946.)

CHAPTER XIII.

30. Outline the life-history of a frog. How are the various stages related to the environment in which it lives?

CHAPTER XIV.

31. Give a labelled diagram to show the form and structure of hydra. What is the fundamental difference between amœba and hydra, and what differences in their life-histories may be related to this? (Ox., 1947.)

32. Compare the reproduction of the earthworm with that of a flowering plant. (C.W.B., 1947.)

CHAPTER XV.

33. With the aid of drawings, describe the structure and reproduction of mucor. Compare its mode of nutrition with that of spirogyra. (Ox., 1946.)

34. Bacteria may live on dead plants and animals. Bacteria help to provide food for plants. Plants provide food for animals. Explain these statements. (L.G.S., 1945.)

35. What is meant by (*a*) a parasite, (*b*) a saprophyte? Describe the method of nutrition of a named parasitic plant. Why is normal nutrition not possible? (N.U.J.M.B., 1946.)

CHAPTER XVI.

36. Name one animal which is a pest. Explain why it is a pest and state how it may be controlled. (L.G.S., 1945.)

37. Explain why the mosquito and the housefly may be dangerous to Man. Describe the methods by which Man may be protected from these dangers. (O. & C., 1945.)

CHAPTER XVII.

38. What is meant by irritability? Illustrate your answer by reference to the irritability shown by hydra and by a seedling. (C.W.B., 1946.)

CHAPTER XVIII.

39. What is meant by a tropic movement? Describe carefully how you would demonstrate a tropic movement of a plant organ. Of what apparent value to the plant is the sort of movement you have demonstrated? (L.G.S., 1947.)

40. Describe experiments to show how and in what part the root of a plant responds to the stimulus of gravity. What other parts of the plant respond to this stimulus and how? (Ox., 1945.)

CHAPTER XIX.

41. What is the difference between reflex and conscious action? Give an example of reflex action and describe its mechanism with the aid of a labelled diagram. (Ox., 1945.)

42. Make a large fully annotated drawing of the eye of a mammal. Explain fully the functions of the iris, lens and retina. (C.W.B., 1947.)

43. Draw a large, fully labelled diagram of the ear of a named mammal. How does the animal (*a*) hear, and (*b*) keep its balance? (No further diagrams required.) (Cam., 1947.)

44. Explain the following phenomena: (*a*) a human being may lose his balance after turning round rapidly several times; (*b*) it is at first difficult to see when going from a lighted room into a darker one; (*c*) to break one's back is more dangerous than to break one's leg. (O. & C., 1946.)

CHAPTER XX.

45. Describe the structure and pollination of any named insect-pollinated flower you have studied. State the functions of the different parts of the flower. (O. & C., 1947.)

46. Draw large, fully annotated diagrams to show all the parts of either one named fruit with a succulent part which aids seed dispersal, or one with an appendage which aids seed dispersal. Describe exactly how dispersal takes place, and state its value. (C.W.B., 1947.)

CHAPTER XXI.

47. What is meant by (*a*) excretion, (*b*) secretion? Describe the functions in a mammal of (*a*) the skin, (*b*) the kidneys. (N.U.J.M.B., 1947.)

48. What is the essential feature of sexual reproduction and what do the offspring require for successful development? From this

point of view, compare and contrast the modes of fertilization and development to mature form in a frog, a bird and a mammal. (Details of stages of development are not required.) (Ox., 1946.)

CHAPTER XXII.

49. Write a brief essay on the important discoveries made by Mendel. (Ox., 1945.)

50. A cross between a homozygous (pure) red snapdragon and a homozygous (pure) white snapdragon gave all pink-flowered offspring. Explain this and state what you would expect to result from self-pollinating this pink-flowered generation. (Ox., 1945.)

CHAPTER XXIII.

51. Explain how you would distinguish the following on external appearances only: (*a*) a male and a female cockroach; (*b*) a queen bee and a worker; (*c*) the larvæ of a house-fly and a butterfly. (O. & C., 1946.)

52. Describe the life-history of the honey-bee, and point out two ways in which it is useful to Man. (Diagrams essential.) (Cam., 1947.)

CHAPTER XXIV.

53. Name three external features of a bird. Explain how the features you mention are related to the life and habits of the bird. (N.U.J.M.B., 1947.)

54. Describe the limbs of a mammal, a bird and a fish, in each case naming the animal. State clearly how these limbs are adapted to the habits of the animal named. (C.W.B., 1946.)

CHAPTER XXV.

55. Describe the seasonal changes in the animals and plants in any one habitat you have studied. In what ways do two animals and two plants survive the winter in this habitat? (Diagrams optional.) (Cam., 1947.)

56. What is meant by a community of plants and animals? Choose any community you have studied, and describe the inter-relationships between the organisms present. (L.G.S., 1945.)

GENERAL.

57. The answer to each part of this question should be as brief as possible. (*a*) Name four characteristic activities of living

organisms. (*b*) What is meant by assimilation? (*c*) What is the principal difference between the nutrition of green plants and animals? (*d*) How does a frog spend the winter, and how does it manage to survive in the manner described? (*e*) Give the name of one flower which is usually insect-pollinated, and the name of the insect which usually pollinates it. (*f*) How would you proceed to show whether starch is present in a green leaf? (*g*) What structures are responsible for locomotion in a fish, and what structures are responsible for balancing the fish in the water? (*h*) Name two distinct parts of the brain of a mammal. (*i*) State two effects of the lack of light on the growth of a young seedling. (*j*) Name one plant in which reserve food is stored in the root, and one in which reserve food is stored in the stem. (*k*) State two differences between a molar tooth of a dog and that of a rabbit (or other named mammal). (N.U.J.M.B., 1947.)

58. Answer briefly any three of the following (each answer taking five or six lines). Distinguish between: (*a*) spinal column and spinal cord; (*b*) pollination and fertilization in plants; (*c*) transspiration and respiration; (*d*) rhizome and root; (*e*) testis and ovary (of a mammal). (L.G.S., 1945.)

59. Give three important reasons for the circulation of blood in a mammal. Explain how plants are able to live without a circulatory system of this kind. (Cam., 1947.)

60. EITHER: (*a*) Why is it important to provide sand and gravel as well as green plants in an aquarium where animals are kept? Name two plants and two animals which can be kept together in an aquarium; note any special features possessed by one of these which adapt it to live in this situation.
OR: (*b*) Using a named example in each case, write an account of one animal which is detrimental to, and one animal which is beneficial to plants growing in a garden, or any other habitat you have studied. (C.W.B., 1946.)

61. In any *named* habitat you have studied, describe
EITHER: (*a*) How the changes undergone throughout the year by a *named* deciduous tree are related to its environment,
OR: (*b*) How the life-cycle of a named animal is related to its environment. (N.U.J.M.B., 1948.)

INDEX

Page-numbers in italics indicate diagrams.

Abdomen, 289.
Abscission-layer, 42.
Absorption, 85.
Accommodation of eye, 246, 301.
Acid, 129.
Acquired characters, 283.
Actions, 121–2.
Adaptations, 283.
Adipose tissue, 112.
Adrenal gland, 132, *269*.
Adrenalin, 132.
Aerobic respiration, 63, 92, 135.
Air, constituents of, 85.
Air bladder, *53*, 300.
Air-spaces, *30*, 32.
Alcohol, 206, 211.
Algae, 196–201.
Algin, 201.
Alimentary canal, *126*, 190, 193, 291, 306.
Alveoli in lungs, *136*.
Ammonia, 71–72, 269.
Amœba, 181, *182*, 183.
Amphibia, 171–79.
Anabolism, 6.
Anærobic respiration, 63, 94.
Ancestry, 283–88.
Animals and plants compared, 9.
Annelids, 188.
Annual plants, 26.
Annual rings, *40*, 41.
Antennæ, 290, *293*.
Anther, *253*, 260.
Antiseptics, 212.
Antitoxins, 218.
Ants, 298.
Anus, 128.
Anvil-bone of ear, *248*.
Aorta, 140, *141*.
Apes, 287.
Appendix, 128.
Aquatic animals, 171, *182*, *184*, *300*.
Aquatic plants, *197*.
Aril, 266.
Artery, 139, *141*.
Arthropods, 289.
Artificial propagation, 106
Asexual Reproduction, 183, 186, 197.
Assimilation, 97.
Auricle, 138, *142*, 178, 307–8.
Automatic muscles, 123, 226, 240.
Autumn, 52.
Auxin, 107, 153.
Axillary buds, *20*, *24*, 48.
Axolotl, 154.
Axon, *238*.
Axon-brush, *238*.

Backbone, 11, *115*, *117*, 177.
Bacillus, *207*.
Bacteria, 68, 73, *207*, 212, 216.
Baking with yeast, 205.
Balance of life, 2, 82, 310–315.
Balance, sense of, 249, 302.
Barberry, 219.
Bark, *40*, 41, 45–6.
Bat, *124*, 247.
Beaks of birds, *306*.
Bean, 157–*159*, 161.
Beauty-vitamin, 79.
Bee, 259, 295, *296*.
Beetles, Colorado-, 215.
Beri-beri, 78, 79.
Biennial plants, 26, 102.
Bilateral symmetry, 112, 254.
Bile, *126*, 127.
Binocular vision, 243.
Biology, purpose of, 1.
Birds, 246, 266, 303–307.
Bladder, *72*, *269*, *270*.
Bladder-wrack, 200.
Blind spot in eye, *422*, 245.
Blood, 143, *144*, 145–6, 178, 191, 307.
Blight, 211.
Blinking, 244.
Blue-mould, 204.
Body-cavity, 188.
Body-lice, 214.
Bone, 114.
Botany, definition, 18.
Bracken, 314.
Brain, *238–9*.
Bread mould, 201.
Breastbone, *115*, *117*, 304.
Breathing, 4, 135–37.
Breeding, selective, 155.
Brewing with yeast, 206.
Broomrape, 208.
Bronchi, 135, *136*.
Budding, 106, *107*.
Buds, winter, 46, *47*, 49.
Buds, summer, 20.
Bulb, *103*. 105.
Bulbil, 106.
Burr, *232*, 266.
Buttercup, *253*.
Butterfly, *293*.

Cactus, 21, *23*.
Cæcum, *126*, *127*, 128.
Calcium compounds, 77.
Calorie, 56.
Cambium, 23, *24*, 26, 40.
Camouflage, 172.
Canals, of ear, *248*, 249.
Cane-sugar, 205.
Canine teeth, 118, *119*.
Capillary-action, 89.
Capsule, 232.
Carbohydrate, 65–69.
Carbon assimilation, 59, 97.
Carbon cycle, 61.
Carbon dioxide, 59, 93, 97–100.

Cardiac muscle, 123.
Carnivorous animals, 59, 119.
Carnivorous plants, 34.
Carrot, 102, *103*.
Carrot-fly, 215.
Cartilage, 114, 117, 308.
Cat, 120, 242.
Catalyst, 129.
Caterpillar, 293.
Catkins, 45.
Cattle-breeding, 155.
Cell, 6.
Cell-division, 149–*150*.
Cell structure, *7*, 8.
Cellulose, 8, 68.
Central nervous system, 237, *238*, *239*.
Cerebellum, *238*, *239*, 240.
Cerebrum, *238*, *239*.
Chætæ, *189*.
Chalk, 164.
Chemical food of plants, 92.
Chemotaxis, 228.
Chemotropism, 233.
Cherry, 258, *264*.
Chicken development, 306.
Chitin, 290.
Chlorophyll, 10, 37, 77, 100.
Chloroplast, 8, 31, 100.
Chromosome, *149*, 278–9.
Chrysalis, *293*.
Cicada, 151.
Cilia, 176.
Circulation of blood, *138–142*, 178, 191.
Classification of organisms, 10–12.
Classification of vertebrates, 307.
Climbing plants, 20, *21*, 34.
Clitellum of earthworm, *189*.
Cloaca, 178.
Clover, *35 208*.
Cnidoblast, *184*, *185*.
Coal, 57.
Coccyx, 116.
Cochineal, 213.
Cochlea, *248*.
Cockroach, *292*.
Cœlenterates, *184*.
Cœlum, 188, *189*.
Cold, common, 212.
Coleoptera, 298.
Cold-blooded animals, 175, 307.
Collar-bone, *117*, 120.
Colour-changes in frog, 175.
Colour-vision, 224, 245.
Columella, 202, *203*.
Communities, 310–15.
Companion cell, 25.
Composite flowers, 36, 253.
Compound eye of insects, 290, 295.
Conduction of water in plants, 89.
Cone-bearing trees, 52.
Conjugation, 198, *199*.
Connecting strands of protoplasm, *7*, 8.
Connective between anthers, *260*, 261.
Constipation, 65.
Contractile roots, *103*, 105.
Contractile vacuole, *182*.
Control experiments, 88.
Control of organisms, 215–220.
Cord, nerve-, *240*.
Cork, *40*, 42.
Corm, *103*, 105.
Corn, Indian, 162.
Cornea, *242*.
Corolla, 254.
Corpuscles, *144*.
Cortex, *24*, *25*, *269*.
Cotyledons, 158, *159*.
Coughing, 129.
Cow's stomach, 133.
Crane-fly, 215, 299.
Cranium, *114*.
Cretinism, 154.
Cross-pollination, 257.
Cross-fertilisation, 276.
Crystalline lens, *242*, 246, 301.
Cuticle, *30*, 31.
Cutein, 25, 31.
Cycle, Carbon, *61*.
Cycle, Nitrogen, 73, *74*, 75–77.

Daisy, *254*.
Dandelion, 16, 254.
Darwin, Charles, 168, 287.
Decay, 72, *74*, 211.
Deciduous plants, 39.
Deep breathing, 137.
Dehydration, 233.
Dendrite, *238*.
Dental formulæ, 118–9.
Dentine, 116.
Dermis, *111*.
Dextrose, 66.
Diabetes, 113.
Diaphragm, 125, *126*, 136.
Diastase, 130.
Dicotyledons, *19*, 27, 157–162.
Diet, 82.
Diffusion, 85–6.
Differentiation, 150.
Digestion, 125–33.
Digits, 121.
Diœcious plants, 258.
Diphtheria, 212.
Disease, 2.
Dispersal of plants, 233–235, 263–66.
Dissection of rabbit, *126*.
Division of labour, 185.
Dodder, *208*.
Dog, teeth of, *119*.
Domestic animals, 213.
Dominance, 277.
Dormancy of frog, 175.
Double circulation, 138, *141*.
Dorsal aspect, 112.
Drone, 295, *296*, 297.
Drugs, 108, 211.
Drum of ear, 176, *249*.
Ductless glands, 132.
Duodenum, *126*, *127*.

Ear, 176, *249*.
Earthworm, 188–192.
Ecology, 169.
Economic importance of animals, 213.
Economic importance of plants, 54, 107, 210.
Ectoderm, *184*, 185.
Ectoplasm, *182*.
Eel, 302.
Egg, 171, 186, 192, 256, 270, 296, 301, *307*.
Elbow, 120.
Elements in protoplasm, 71.
Embryo, 157, 271.
Enamel on teeth, 116.
Endocrine organs, 132.
Endoderm, *184*, 186.

Endogenous, 37, 161.
Endoplasm, *182*.
Endo skeleton, 292.
Endo sperm, 262.
Energy, 56–63.
Enteron, *184*.
Environment, 2.
Enzymes, 129, 206.
Epicotyl, 161.
Epidermis, *24*, *30*.
Epiglottis, *127*, 129, *136*.
Equilibrium (sense of balance), 249, 302.
Etiolation, 100.
Eustachian tube, 247, *248*, 249.
Evaporation and cooling, 81.
Evergreen plants, 39.
Evolution, 284.
Excretion, 81, 268–*270*.
Exercise, 62, 68.
Exoskeleton, 292.
External parasites, 214.
External skeleton, 290, 292.
Eye, 175, 241, *242*–246, 290, 301, 305.

Factor in heredity, 276.
Fæces, 131.
Family resemblance, 274.
Fangs of snake, 303.
Fat, 69, 112.
Fatigue, 63.
Feather, 305, 308.
Feeler, 290.
Feet of birds, 266, 305.
Femur, *115*, *117*, 120, *121*.
Fermentation, 206
Fertilisation, 206, 211.
Fertilisers, 76.
Fever, 212.
Fibres in plants, 23, *24*, *25*.
Fibrin, 145.
Filament, 253.
Finger-nails, 71, 112.
Fins, *301*.
Fish, *301*, 302.
Fission, 183, 197, 207.
Fleas, 214.
Flies, 294.
Flowers, 252–256.
Follicle, hair-, *111*.
Food, 65–83, 182, 193, 289.
Foot, *121*, 295, 305.
Formaldehyde, 97.
Fossils, 285, 286.
Foxglove, 36, 208.
Fragmentation, 197.
Friends, biological, 187, 209, 210–220.
Frog, 171–*178*.
Fruit, 108, *232*–235, 263–266.
Fucus, 200.
Fuel for energy, *57*, 59.
Fungus, 201–5.
Fusion of gametes, 198, 262.

Gall-bladder, *127*.
Gall-flies, 298.
Gametes, 198, 276, 278.
Ganglion, 238.
Gas exchange in animals, 4, 59, 135–37.
Gas exchange in plants, 4, 59, 92–100.
Gene, 279.
Genus, 11.
Geotropism, *229*.
Germination, 159, 160–4.
Germs, 295.
Gestation, 271.
Gill of fish, 300.
Giraffe, 115.
Girdles, *115*. *117*, 120, *178*.
Glands, 132.
Gliding, 53.
Glucose, 66.
Glycerine, 66.
Glycogen, 62, 67.
Grafting, 106, *107*.
Granules, *67*, 182.
Grape sugar, 66.
Gravity and plants, *229*.
Green algæ, 196–200.
Gregarious animals, 113.
Grey matter, 238–*240*.
Growing-point, 15.
Growth, 148–55.
Guano, 76.
Guard-cells, *30*, *90*, *91*.
Gullet, *126*, 127.

Habit, 18.
Hæckel, 282.
Hæmoglobin, 143, 191.
Hæmophilia, 281.
Hair, *111*, 295, 308.
Hammerbone of ear, *248*.
Harvey, William, 138.
Healing, 192.
Health, 218.
Heart, 62, 132, *141*, 142.
Heat and organisms, 151–2, 163.
Hepatic portal vein, *141*, 142.
Herbaceous plants, 14.
Herbivorous animals, 57, 118.
Heredity, 274—282.
Hermaphrodite, 191.
Herrings, 304.
Hibernation, 175.
Hilum, 156, *159*.
Homing instinct, 304.
Hormones, 107, 146, 153.
Horse, fossil history, 285.
Horse chestnut, *47*.
Host, 193, 208.
Housefly, 294–5.
Human ancestry, 287–8.
Humus, 164, 211.
Hybrid, 277, 278.
Hydra, *184*–187.
Hygiene, 218.
Hymenoptera, 298.
Hypha, 202.
Hypocotyl, *159*, 161.
Hypostome, *184*, 185.

Ichneumon, 293.
Imago, 294.
Incisors, 117, *118–9*.
Incubation, 307.
Incus bone, *248*.
Individuality, 148, 150, 283.
Infancy, variation in duration, 272.
Inhale, 135.
Inheritance, 276.
Inoculation, 218.
Inorganic salts, 77, 91.
Insects, 289–99.
Insulin, 132.
Internal skeleton, 114–*121*, *177–8*.
Internode, *43*, 49.
Interstitial cells, 185.
Intestine, *126*–128, 190, 192.
Invertebrates, 11, 181–194, 289–299.
Involuntary muscle, 123, 225.

Iodine in organisms, 77.
Iris of eye, *242*.
Iris plant, 27, 253.
Iron in organisms, 77, 92.
Irritability, 222–226.
Ivy, *21*, 29.

Jaws, 116, 294, 303.
Jellyfish, 184, 186.
Jenner, 218.
Joints, types of, *114*, 116, *120*.
Juices, digestive, 129, 130.

Kangaroo, 271.
Katabolism, 6.
Keel of flower, *259*.
Keratin, 112.
Kidney, 131, *269*.
Klinostat, *230*.
Knee, 121.
Kingdoms, animal and plant, 11.
Koch, Robert, 216.

Lacteal, 131.
Lactic acid, 62.
Lamarck, 283.
Lamina, 27.
Larva, 154, *172*, *293*, 294, 297, *298*.
Larynx, 135, *136*.
Leaching, 168.
Leaf, 27–35.
Leaf-fall, *42*.
Leaf-mosaic, 101.
Leguminous plants, *73*, *259*.
Lens of eye, *242*, 246, 290, 301.
Lenticel, 42, 47, *48*.
Lice, 214.
Lichen, 209.
Ligament, *242*.
Light and plants, 101, 230.
Lignin, 23.
Limbs, 120–*122*, *123*, 176, *178*, 290, *301*–2, 303.
Linnæus, 11.
Lipase, 130.
Liver, *126*, *127*, 131.
Living, things characteristics of, 4.
Locomotion, 4, 121, 183, 187, 189, 302, 303.
Locusts, 215.
Lumbricus (earthworm), 188–92.
Lungs, 125, 135.
Lymph, 131, 146.
Lymphatics, *141*.

Magnesium in plants, 77, 92.
Maize, 162.
Malaria, 214.
Malleus bone, 248.
Malpighi, 111, 291.
Malpighian layer, 111.
Maltose, 66.
Mammals, 110–46, 237–251, 268–88.
Mammary glands, 113.
Marrow in bones, 145.
Measles, 212.
Medicine and biology, 2, 215, 216.
Meiosis (reduction-division), 278.
Membrane, semipermeable, 87, *88*, 89.
Mendel, 275–78.
Meristem, 150.
Mesentery, 128.
Mesoderm, 188.
Mesoglea, *184*, 186.
Metabolism, 6.
Metacarpal, *121*.
Metamorphosis, 153, *172*, 174, 293–6.
Metatarsal, *121*.
Metazoa, 184.
Micropyle, 157, *159*, 261.
Microscope, 75, 196.
Migration, 303.
Milk, 78, 113.
Mineral salts in organisms, 77, 91.
Mistletoe, 208, 265.
Mitosis (cell-division), 148, *149*.
Monocotyledons, *16*, *19*, *104*, 105, 162–3, 253.
Monœcious plants, 258.
Monosaccharide, 66.
Moss, 234.
Moths, 293.
Motor nerve, 238, *240*.
Motion in organisms, 121, 222–235, (see also locomotion.)
Moulds, 201.
Mucus, 175, 188, 196.
Mucor, 201, *203*.
Muscle, *122*–123, 129, 136, *189*, 242, 247, *291*, 303.
Mushroom, 205.
Mycelium, 202, *203*–205.

Naming of organisms, 10.
Nastic movements, 233.
Natural selection, 287.
Nectar, 253.
Nephridia, *189*, 190.
Nerve cell, 185, *238*.
Nervous system, 224, 237.
Neuron, 238.
Newt, 170, 179.
Night-vision, 245.
Nitrogen in plants, 71–7.
Nitrogen cycle, 73–75.
Nodules on plant-roots, 73.
Non-flowering plants, 12.
Non-living things, 3.
Nucleus, *7*, 8.
Nutrition, 4.

Oil, 69–70, 163, 266.
Olfactory sense, 250.
Omnivorous animals, 57.
Onion cells, *7*, 8.
Onion bulb, 105.
Opium, 211.
Optic nerve, *242*, 245.
Orchid, pollination of, *260*.
Organ, 7.
Organic, 65.
Organism, 5.
Osmosis, 85–*88*.
Osmotic pressure, 87.
Ovary, *184*, 256, *261*, *270*, *292*.
Oviduct, *270*, *292*.
Ovipositor, 296.
Ovule, 256, *261*.
Oxidation, 59.
Oxy-hæmoglobin, 144.

Pain, 250.
Palate, *127*, 128–9, *136*.
Palisade tissue, *30*, 31.
Palmate venation, 29.
Palps, 290.
Pancreas, *126*, *127*.
Parasites, 214.

Parental care, 272, 370.
Pasteur, 216.
Patella (knee-cap), *117*, *122*.
Peas, *232*, 266, 275.
Pectoral fin, *301*, 302.
Pectoral girdle, *115*, *117*, 120, *178*.
Pellagra, 79.
Pelvic fin, *301*, 302.
Pelvic girdle, *115*, *117*, 120, *178*.
Penicillin, 2, 204, 211.
Penis, *269*.
Pepsin, *129*.
Perennial plants, 27, 102.
Perianth, 253.
Pericardium, 126.
Pericycle, 25.
Permeability, 86.
Perspiration, 81, 268.
Petiole, 27, *29*.
Phalanges, *121*.
Pharynx, 129, *136*.
Phlœm, *24–5*, *40*.
Photosynthesis, 59, 97.
Phototropism, 230.
Pigment, 175.
Pine, 52.
Pinnate leaf, 29.
Pistil, 255, 258, *259*.
Pith, 25.
Pituitary gland, 132, 154.
Plague, 214.
Plankton, 310.
Plants and animals, compared, 9.
Plasma, 143, 145.
Plastids, 8, (see also chloroplasts).
Platelets, *144*.
Pleurococcus, 200, *203*.
Ploughing, 75, 212.
Plumule, 158, *159*.
Pod, *232*, 234, 264.
Poisons in blood, 146, 214.
Pollen, 255, *261*.
Pollen basket, brush and comb, 296.
Pollination, 257.
Pondweed, *99*.
Pond life, 311.
Pores, 28, *111* (see also stoma).
Porifera (sponges), 184.
Portal vien, *141*, 142.
Postcaval vein, *141*.
Potato, 104, *105*.
Prickly pear, 220.
Propagation, vegetative, 102–*105*.
Propagation, artificial, 106, *107*.
Proteins, 71, 268.
Protoplasm, 6.
Protozoa, 181.
Ptyalin, 129.
Public health, 220.
Puffballs, 205.
Pulmonary circulation, 140.
Pupa, *293*, *295*, *297*.
Pupil of the eye, *242*, 244.
Pure strain, 275.
Pyloric sphincter, 130.
Pyrenoids, 197, *199*.
Pythium, 211.

Queen bee, 295, *296*, 297.

Rabbit, 111.
Radial symmetry, 254.
Radicle, *159*–161.
Radius bone, *121*.
Rat, 214.
Recessive character, 276–7.
Rectum, *126*–128.
Red corpuscles, 140, *144*.
Reduction division, 278.
Reflex action, 225, *240*.
Regeneration, 150, 192.
Renal portal vein, 142.
Rennin, 129.
Reproduction, 4, 252–266, 268–273, etc.
Respiration, 4, 92–5, 135–137, etc.
Retina of eye, *242*, 243.
Rhizome, 102.
Ribs, *115*.
Rickets, 79.
Ringworm, 205.
Rods and cones, 245.
Root, 14–*17*, *40*.
  hairs, 15, *17*.
  nodules, *73*.
  pressure, *88*.
Rotation of crops, 75.

Sacrum, 116.
Salamander, 154.
Saliva, 128.
Salts and Plants, 92.
Saphrophytes, 201–7.
Scars, 47.
Scale insects, 213.
Schwann, Theodor, 6.
Scientific method, 274.
Scion, *107*.
Seaweed, 200.
Seeds, 157–164, 262, 266.
Segmentation, *172*.
Segregation of characters, 276.
Semicircular canals, *248*.
Seminal vesicles, *191*, *269*.
Sense organs, *240*-251.
Sensitive plant, 226, 233.
Sepals, *253*.
Septa in earthworm, *189*, *191*.
Serum, 145.
Sessile organisms, 187.
Sewage farms, 76.
Sexual reproduction, 198, (see also reproduction).
Shark, basking, 300.
Sheep's heart, *142*.
Sieve-tubes, 24, *25*.
Sight, 224.
Silk, 293, 298.
Skeleton, 114, 290, etc.
Skin, 111.
Skull, 116, *117*, 177, *178*.
Smallpox, 218.
Smell, sense of, 250.
Snake, 303.
Soil, 164–69.
Spallanzani, 216.
Species, 11.
Sperm, 179, 192, 270.
Sphincter, 130, 131.
Spiders, 289.
Spinal cord, *240*.
Spiracles, 291.
Spirillum, *207*.
Spirogyra, 196–*199*.
Spleen, 145.
Spontaneous generation, 216.
Spores, 202, *203*, 234.
Stamen, *253*–261.
Stapes bone, *248*.
Starch, 32, 62, *67*, 68.
Stem, 18, *19*-26.
Stereoscopic vision, 243.
Stickleback, 272.
Stigma, *253*–261.
Stimulus, 4, 222–3, 226, 227.

Stirrup bone, *248*.
Stomach, *126*, *127*, 129.
Stoma, *30*, 32, *90–91*.
Storage of food, 62, 67, 69, 102–*105*.
Succulent stems, 21, *23*.
Suckers, *105*.
Sucrose, 66.
Sugars, 66.
Sunflower, 26, 230.
Suprarenal (adrenal) glands, 132, *269*.
Swallowing, 129, 135.
Sweat-glands, 81, *111*, 268.
Symbiosis, 187, 209.
Symmetry, 112, 254.
Sympathetic nervous system, 225, 241.

Tadpole, 154, *172*–174.
Tænia, *193*.
Tapeworm, *193*.
Tarsus, *121*.
Taste, 250.
Taxis, 228.
Teeth, 116, *118–119*.
Temperature control, 81, 146, 269.
Tendon, *122*.
Tendril, *34*.
Tentacles, *184*.
Testes, *184*, *269*.
Thorax, 115, 125.
Thymus gland, *126*, 132.
Thyroid gland, *126*, 132, 154.
Tibia, *117*, *121*, *122*.
Tissue, 7, etc.
Toad, 171, 179.
Toadstool, 205, 211.
Tongue, *127*, *136*, 250.
Touch, sense of, 250.
Trachea, 125, *126*, *136*.
Transpiration, 30, 81–2, 89.
Transportation of food, 33, 62, 67, 128, 131, 146.
Trees, 39–54.
Tropisms, 228–233.
Trypsin, 130.
Tsetse fly, 214.
Tuber, 102, *103*, 104.
Turnip, *103*.
Twigs, 46, *47*.
Typhoid, 212.

Ulna, 117, *121*, *122*.
Urea, 269.
Ureter, *269*, *270*.
Urinary organs, *269*, *270*.
Uterus, *270*.

Vaccination, 218.
Vacuole, *7*, 8, *182*.
Vagina, *270*.
Valves in veins, *139*.
Vascular bundle, *24*, 25, 40.
Vegetal, cells, 173.
Veins, 139, *141*.
Vena cava, *141*.
Venus' flytrap, *34*.
Ventral aspect of animals, 112.
Ventricle, 138, *142*, 178, 307–8.
Vertebral column, 114, *115*, *117*, *178*.
Vertebrates, 12.
Vessels in plants, 23–*25*, *40*.
Vestigial organs, 285.
Villus, *130*.
Virus, 212.
Vitamin, 78, 79.
Viviparous animals, 308.

Warm-blooded animals, 307.
Wasps, 297.
Water in organisms, 80, 85, etc.
White corpuscles, *144*.
White matter, 238, *240*.
Windpipe, see trachea.
Winged fruits, *25*, 235, 266.
Wings of birds, 303, 305.
Winter twigs, 46, 47.
Woods, 313–4.
Worker bee, 295, *296*.

Xerophyte, *34*.
Xylem, 23, *24*, *40*, etc.

Yeast, 94, 205.
Yellow fever, 218.
Yellow spot in eye, *24*
245.
Yolk, 173, *307*.

Zoology, 18.
Zygospore, 198, 204.
Zygote, 199, 276, 278.